

# Effect of Kenaf Fibre Layers on Mechanical and Thermal Properties of Kenaf/Unsaturated Polyester Composites

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**Abstract.** Composites of kenaf/unsaturated polyester containing 1 layer up to 4 layers of kenaf fibre were studied to evaluate the mechanical and thermal properties. These composites were compared with a control system containing unsaturated polyester. The composite of different fibre layers was prepared using compression moulding techniques. The composites with x layers had the lowest tensile strength with slightly higher flexibility compared with those systems containing higher number of layers. The tensile properties of composites containing x layers demonstrated that the addition of fibre to the kenaf/unsaturated polyester composite was affected more than the incorporation of the. Thermogravimetric analysis of pure kenaf, unsaturated polyester and unsaturated polyester composite incorporated with 1, 2, 3 and 4 layers revealed significant differences in the decomposition temperature. Analysis by differential scanning calorimetry, equally, showed a decrease in thermal transitions with the 1 through 4 layers. The results of the mechanical and thermal properties tests suggest that kenaf fibres improved the composite mechanical and thermal properties.

## 1. Introduction

The development of biodegradable material yet mechanically capable based on natural materials is expected to grow for the next 2 to 3 decades [1,2]. The fibre based biodegradable polymer composite materials with good mechanical and thermal properties has attracted the attention of research communities recently (The trend interest is expected to grow in daily basis as the materials have high potential for various applications [1-10]. Due to this requirements, there is need to improve its degradability [11-18]. This degradability is improved by treated and several treatment approaches have been proposed for example [6-8] have proposed hydrogen peroxide on Kenaf Fiber/Poly(Lactic Acid) Composites, several have been reported such increase in crystallinity index and surface roughness of the kenaf fiber which improved mechanical properties of the prepared composite, however, this in essence of removing some vital parts in the composite such as lignin and hemicellulose [19-30]. The development of biodegradable material yet mechanically capable based on natural materials is expected to grow for the next 2 to 3 decades [1,2]. This is mainly due to their environmental advantages over other materials [3]. In recently, natural fibre-based polymer



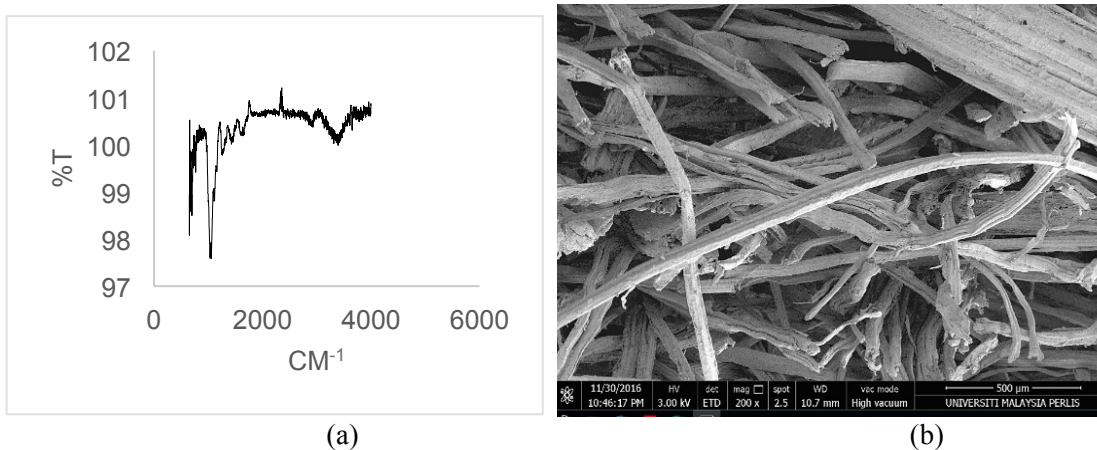
composites have been proposed in several applications due to natural materials offering wonderful properties such as lightweight [4], ease of fabrication [5], cheap and environmentally friendly [6]. The mechanical properties of the material are suitable for many applications [6]. Its application are found in many moving devices especially in aerospace where light and mechanical strength are crucial. The kenaf fibre equally provides very high values of the hardness and strength [7]. Moreover, the material has higher aspect ratio due to its orientation compared to other types of fibres [8]. It offers interlocking ability where polymer molecular movement are hampered (restraining the intermolecular sliding) using as a polymer composites reinforcement is favourable and will allow mechanically suitable composite [9]. The kenaf generally a *Hibiscus cannabinus*, the family of *Malvaceae L.* which contain several longitudinal and transverse fibre crossing, it is a perennial plant in most part of Asian countries and equally harvested twice depending on the weather condition and other climatic condition [2, ]. Moreover, the fibres attracted the several interests due it potential features; it is inexpensive[5], lightweight[9], high mechanical property and biodegradability which could be used for green technology promotion[10]. However, the real kenaf interaction with polymer matrix and its natural orientation has not been established because most of the researchers mixed it with the matrix after grinding the kenaf which by then the effect of orientation is totally compromised. Therefore, this study proposed integration of kenaf mat into polymer matrix in its natural orientation form to establish mechanical and thermal behaviour to its mat layers in the polymer matrix. Moreover, proposed reinforcement of kenaf unsaturated polyester composite with glass fibre, the study enhanced the adhesion between the surface of fibre and the matrix which that allowed improving the mechanical properties of the KG-UPE hybrid composites prepared, however, this might come with getting the composite more toward nonbiodegradability [31-40]. Several researchers proposed alkaline treatment on kenaf/epoxy composite and found alkali treatment increased the mechanical properties of the composites by allowing improvement of fiber–matrix compatibility, similarly, the chemical treatment bring about lignin and hemicellulose removal or degradation The compatibility between fibre–matrix interface adhesion is the most significant parameter that determine the properties of composites[41-45]. One of the important issues related to natural fiber is the hydrophilic property of cellulose which has an impact on the weak interface bonding with hydrophobic polymer as a matrix[46]. The methods of chemical surface modifications of natural fiber have been proposed by many studies, this include chemical treatment such alkaline most of the this treatment removes lignin and hemicellulose [47-49]. however, this have overall effect on the overall mechanical properties of the composite, the search for the alternative materials have occupied the mind researcher in the field. Recently zinc oxide have been proposed to be used in killing bacteria. The treatment mechanism are as follow, immersing the the zinc ion ( $Zn^{2+}$ ) into aqua ions, it formed water ligands with hexa and tetra-aqua ions, the reaction of the ion with hydroxide through donation of a proton on the surface of the fibre [1,2, 46-51].

## 2. Methods

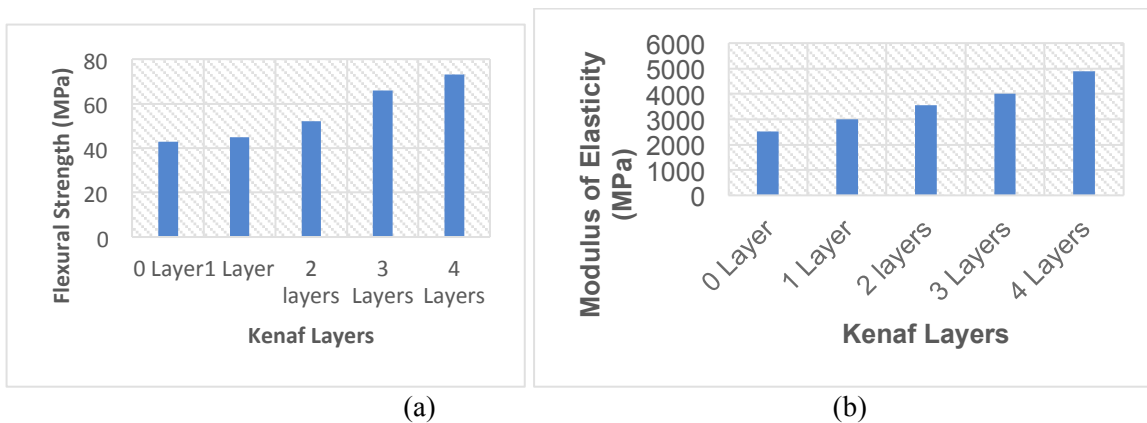
The section describe the methods and materials of this study. The bundle of pure Kenaf fibre was obtained and purchased from Rahamatullah Sdn. Bhd (Kedah, Malaysia) in Petani, Kedah Malaysia. The kenaf was in the mat form and used as received without any further treatment. A standard unsaturated polyesters resin was supplied by Castmesch Technologies Sdn. Bhd. (Perak, Malaysia). Methyl ethyl ketone peroxide (MEKP; solution in dimethyl phthalate) was obtained from Kaumjung Akzo Nobel Peroxide Ltd. (Tianjin, China) by the trade name Butanox M60. unsaturated polyester (UP), and MEKP UP had a hazy pinkish colour with a gel time of 18 min to 23 min at 25 °C with 2% MEKP. The density of the UP was 1.4 g/cm<sup>3</sup> with a specific gravity of 1.12 g/cm<sup>3</sup> and a volumetric shrinkage of 8%. The MEKP was colourless in appearance with a density of 1.15 g/cm<sup>3</sup> with a melting point of -8 °C and a boiling point of 109 °C. The fabrication and testing consisted of 7 major steps. The initial step was the Kenaf fibre mat being cut into 20 cm × 20 cm dimensions. Matrix mixing was done using high speed mixing with a Ragogna mixer custom built for FPIInnovations by Custom Machinery Ltd. (Ontario, Canada) with a speed up to 5,000 rpm was employed. To avoid destabilization of the emulsion, a moderate mixing speed (up to 2,500 rpm) at room temperature. The kenaf fibre layers were placed in a conventional oven to dry at 80 °C overnight.

### 3. Results and Discussion

The figure 1 show FTIR analysis was carried out for the characteristics of the kenaf fibres properties. From the graph, the Fourier transform infrared (FT-IR) spectrum of pure kenaf revealed sharp peak at  $2973\text{ cm}^{-1}$  which is mainly attributed to the single hydrogen bonded O-H which is stretching a lower intermolecular revival phenomena (Lee et al, 2017). Moreover, the peak at  $1323\text{ cm}^{-1}$  as a results of hydro carbonic interaction reaction which mainly due to the characteristic of C-H asymmetric and symmetric stretching (Intan et al, 2014). This is related to the aliphatic groups in cellulose and hemicellulose. Another peak at  $1739\text{ cm}^{-1}$  corresponds to ester carbonyl vibrations from the acetyl, feruloyl and p-coumaryl groups in lignin. A stretching peak detected at  $936\text{ cm}^{-1}$  is attributed to the carbonyl group of the acetyl ester in hemicellulose and the carbonyl aldehyde in lignin. The broad peaks at  $1352\text{ cm}^{-1}$ ,  $1451\text{ cm}^{-1}$  and  $1641\text{ cm}^{-1}$  are corresponds to C-O vibration



**Figure 1.** FT-IR spectrum of pure kekaf fibres (b) The pure kenaf prior to composite process

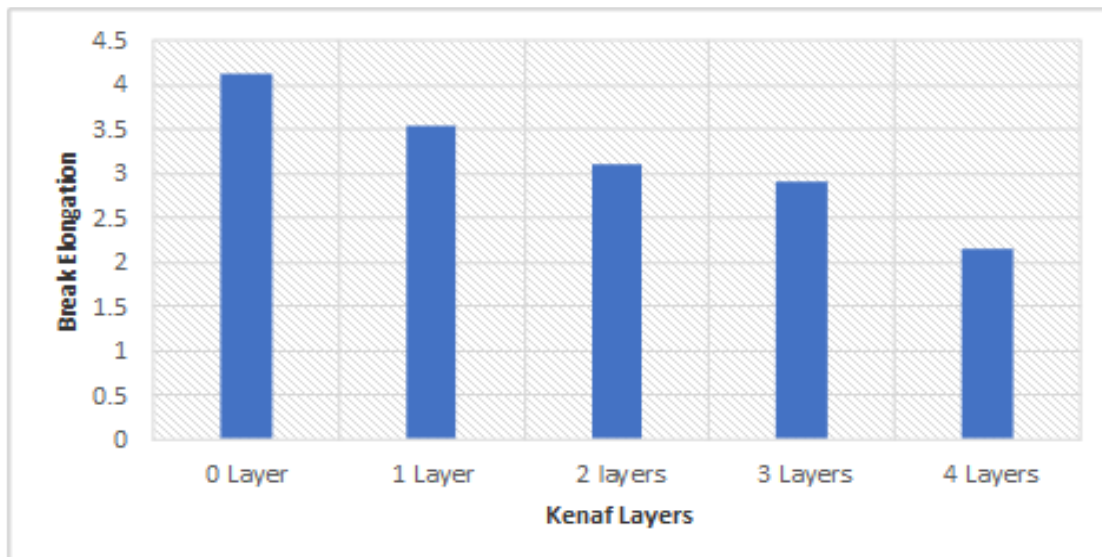


**Figure 2.** (a) Flexural strength of composites for 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf (b) Modulus of elasticity of composites for 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf.

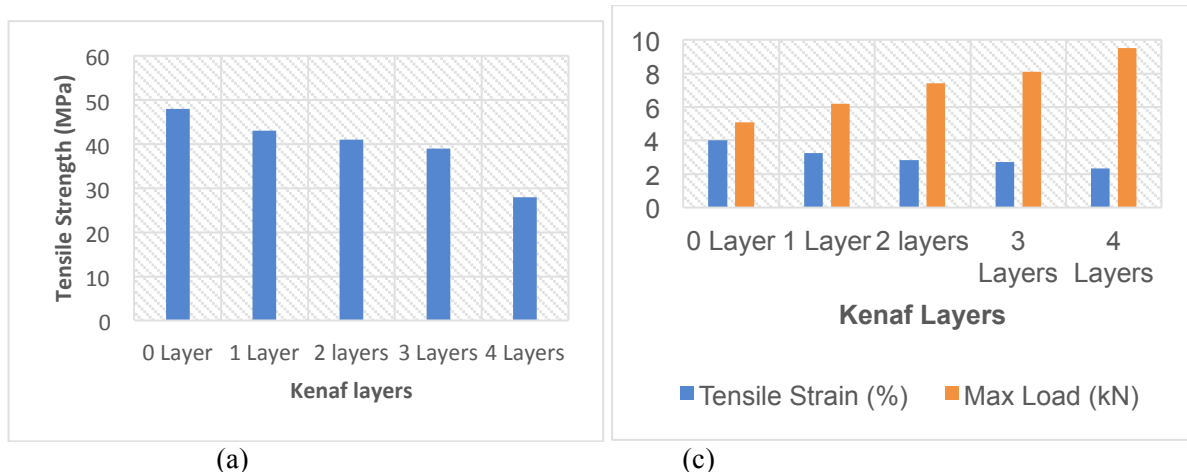
To the investigate the mechanical properties of the prepared composite, a flexural test was conducted. The see the effect of kenaf mat layers, composite with 0 layers, 1 layers, 2layers, 3 layers and 4 layers were tested, the zero kenaf system with only UP shows a flexural strength value of 43.1MPa. The value of the flexural increased to 56.5 PMa with addition of 1 kenaf layer. The 2 layers composite produced the 51.6MPa, with addition of other layers making it 3 layers increased the flexural strength to 66.2PMa and likewise addition of additional layer observed similar trend with 73MPa. The continual increase in flexural strength revealed a clear evidence that kenaf may have effect on the mechanical properties of the kenaf, in the other hand, it shows the kenaf gives some compatibility

between its with matrix. The process of cool compressed have equally greater effect in producing non-voids composite, it allows homogenous compressed. The study conducted by Netnapa et al, 2016 does not show the trend of flexural increased due to voids in the composite. According to their study, the reduction in flexural properties were observed and this might be due to void content and inhomogeneous distribution kenaf in the matrix. Moreover, the flexural further decrease with thermal retardant filler added, this might be the interfacial adhesion between natural fiber and polymer matrix was thermal affected by the retardant filler and equally shows the Modulus of elasticity composites 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf. The 0 layers, 1 layers, 2layers, 3 layers and 4 layers kenaf showed a similar trend as flexural strength seen in the previous section. The Modulus of elasticity increased by increasing with 0 layers through the 4 layers kenaf. The addition of 1 layer 2514 to 3000 MPa which almost 20% increase. Similar improvement can be observed from the 2 layers to the 4 layers kenaf. By looking at the two extreme zero kenaf and maximum kenaf layers of 4. The addition of can be seen with comparison of zero and 4 layers Modulus of elasticity was very much different with 2514 MPa and 4993 MPa over 100% increase. The reason is due to promoted compatibility and interfacial adhesion between KF and its matrix because of the cool compression. The results of this finding show similar trend with many researchers [ 5, 7, 9, 11].

Figure 3: The elongation at break of composites 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf. Figure 6 presents the effects of various of kenaf layers on the break elongation of the composites. The 1, 2, 3, or 4 kenaf layers were prepared and as expected, the break elongation of these composites generally decreased with increased kenaf layers. This suggested that the presence of the kenaf fibres increased the stiffness of the composite and does not contribute to the elasticity or the final composite flexibility as equally observed by Tawakkal *et al.* (2014) in their study. Zero kenaf layers initially showed a 4.5% elongation in an untreated composite and gradually decreased from 4.5% to 4.2%, 3.8%, 3.3%, and 2.8% for 1 layer, 2 layers, 3 layers, and 4 layers, respectively. This was due to an ability to withstand the load transfer from the matrix

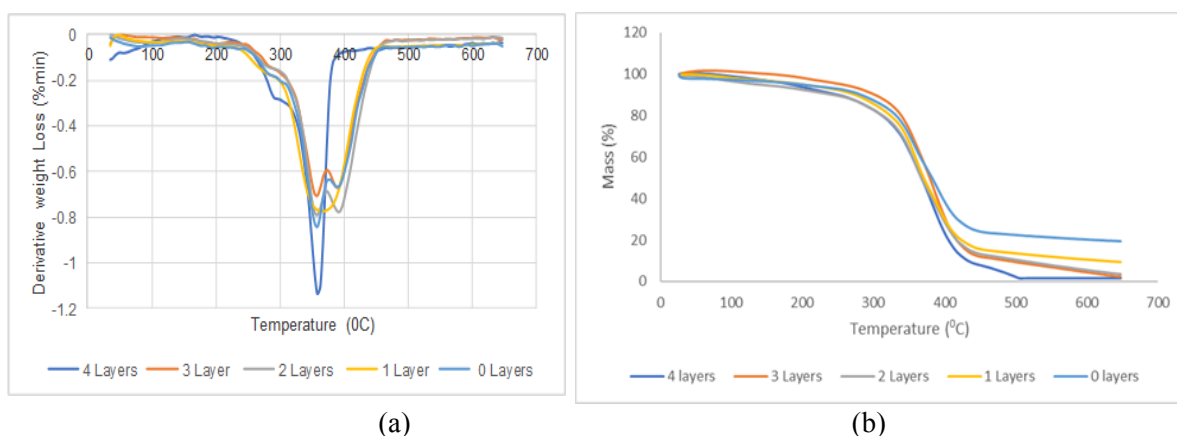


**Figure 3.** (a) Tensile strength composites of 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf



**Figure 4:** (a) show the tensile and max load Kenaf/ polyester composite for 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf (b) tensile stress load Kenaf/ polyester composite for 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf

Figure 4a. Represents the tensile strength of the pure kenaf composite with the corresponding 0 layers, 1 layer, 2 layers, 3 layers, and 4 layers of kenaf mat. It was shown that the kenaf layer of 1 composite showed highest tensile strength compared to the compared to other layers composite. This was attributed to the fact that matrix entered into the fibril orientations of the kenaf, as well as the kenaf polymer interface. This interference subsequently moderately improved the mechanical properties. The tensile strength of the of composite was  $55 \times 10^{-6}$  Pa, the 0 layers,  $48 \times 10^{-6}$  Pa for 1 layer,  $40.4 \times 10^{-6}$  Pa for 2 layers,  $38 \times 10^{-6}$  Pa for 3 layers,  $28 \times 10^{-6}$  Pa for 4 layers. With a linear decrease in tensile, which made this an important attribute due to its effect on the biodegradability of the composite. Moreover, the layers of the kenaf improve the stiffness of the composite., its shown the layers of the kenaf have noticeable effect. The addition of a layer decrease the tensile strength from  $55 \times 10^{-6}$  Pa to  $39 \times 10^{-6}$  Pa to  $28 \times 10^{-6}$  Pa, almost a 50% decrease in tensile strength in nontreated composites. Figure 4b abd c show the tensile and max load Kenaf/ polyester composite for 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf, the composite was successfully prepared with in five (5) different layer arrangement 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf. From the figure 8, it evident that there is a decreasing of the tensile strain due to increasing in kenaf from 0 layers, 1 layers, 2layers, 3 layers and 4 layers kenaf. This might be as result of formation of intermolar boding becoming weak and incompatibility of cellulose with the polymer matrix. However, the composite resistance to the load increase, this strongly of affects layers on the mechanical properties of composites. The figure 8 is evident that Load resist to failure has been improved by the inclusion of kenaf fibre layers in the composite.





**Figure 5.** (a) Thermogravimetric DTG of 0 layers, 1 layers, 2layers , 3 layers and 4 layers kenaf (b) thermo-gravimetric analysis (TGA).

The figure 5a show Thermogravimetric DTG of 0 layers, 1 layers, 2layers, 3 layers and 4 layers kenaf analysis , it was done to observe weight loss occurring on natural fibres. The thermogravimetric analysis curves of kenaf polymer composites pure kenaf composites displayed three peaks of weight loss for 0 layers, 1 layers, 2layers , 3 layers. The first stage occurs at temperature range from 210°C due to release of moisture which was absorbed by natural fibre. At the second stage, the major degradation occurred with temperature range at about 290-370 °C, which was related to degradation of hemi cellulose and cellulose of natural fiber. The third stage of weight loss occurred at temperature range at about 460-600 °C, which was related to degradation of lignin. The TGA curves are shifted to lower temperatures, showing a decrease in the thermal stability for both unsaturated polyester and its composites. the kenaf composite thermal stability appears to improve from 140 to 230°C with increase layers of kenaf from 1 to 4 layers. Although, there is a quite small however revealed noticeable trend from the beginning of curve profiles of the composites. The degradation is appeared to be due to the presence of water in the kenaf fibres. Moreover, the figure 10 shows the thermogravimetric analysis profiles of neat kenaf composites containing 0, 1, 2, 3 and 4 layers of kenaf in the form mass percentage as a function of temperature, with all the samples show three major positions of mass losses in the temperature ranges of 280–320°C, 350– 400°C, and 500–650°C. With 1-layer kenaf show earlier loss, the thermal stable increased with number of kenaf layers increase. The 1-layer kenaf composite show stability at temperature 0-200°C, beyond this, it stated to loss mass earlier compared to other kenaf layers arrangement. The other kenaf arrangements show improved stability with the kenaf layers increase, all the remaining three system show similar thermal behaviour. It can be observed from the figure there is a mass% loss from 350– 400°C and with high decomposition temperature of 370°C corresponding to the decomposition of the hydroxyl component of the fibre while major decomposition occurring at the temperature at approximately 390°C corresponds to the lignocellulosic components in the fibre.

#### 4. Conclusion

The characterization kenaf fibres composites was successfully conducted. The characterization was conducted based on mechanical and thermal. With different kenaf layers from 1 to 4 layers. The results showed that as the number of layers increase, it imparts the mechanical properties positively. the The tensile strength and stiffness of kenaf composites however increased with with increased loadings thereby imparting a reinforcement effect within the composite. Moreover, it was found that an acceptable tensile strength was attained by the only 1 layer of kenaf layer in the composites. The TGA analyses. The TGA results also suggested that thymol can be released from the PLA/kenaf matrix at relatively low temperatures and as such has the potential to impart AM activity. Further work in the laboratory is currently under way to evaluate the water absorption from these systems and their subsequent AM activity in order to develop effective active food packaging materials.

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#### References

- [1]. Mohammed M. Rozyanty R., Azlin F. O., Tijjani A., Hashim U., Aeshah M. M., Nik. Z. N., Omar S. D., and Bashir O. B.. (2017a). The weathering effect in natural environment on kenaf bast filled unsaturated polyester composite and integration of nano zinc particle for water repellent, *Micro and Nanosystem* 9(1), 16-27. DOI: 10.2174/1876402909666170531075138

- [2]. Mohammed M., Rozyanty R., Tijjani A. and Bashir O. B., (2017b). ZnO characterization, UV and photocatalysis mechanism for water repellent phenomena in polymer poly composite, in: AIP Conference Proceedings 1885, City, Country, Article ID 020215. DOI: 10.1063/1.5002409
- [3]. Inani Nur Abdul Razak, Nor Azowa Ibrahim, Norhazlin Zainuddin, Marwah Rayung and Wan Zuhainis Saad (2014) The Influence of Chemical Surface Modification of Kenaf Fiber using Hydrogen Peroxide on the Mechanical Properties of Biodegradable Kenaf Fiber/Poly(Lactic Acid) Composites, *Molecules* 2014, 19, 2957-2968
- [4]. Atiqah A., M.A. Maleque, M. Jawaid, M. Iqbal Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications, *Composites: Part B* 56 (2014) 68–73
- [5]. Susheel Kalia, Kamini Thakur, Annamaria Celli, Marjorie A. Kiechel, Caroline L. Schauer (2013) Surface modification of plant fibers using environment friendly methods for their application in polymer composites, textile industry and antimicrobial activities: A review, *Journal of Environmental Chemical Engineering* 1 (2013) 97–112
- [6]. Fiore V., G. Di Bella, A. Valenza (2015) The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites, *Composites: Part B* 68 (2015) 14–21
- [7]. Ramesh M., K. Palanikumar, K. Hemachandra Reddy (2013) Comparative Evaluation on Properties of Hybrid Glass Fiber- Sisal/Jute Reinforced Epoxy Composites, *Procedia Engineering* 51 (2013) 745 – 750
- [8]. Michael P.M. Dicker, Peter F. Duckworth, Anna B. Baker, Guillaume Francois, Mark K. Hazzard, Paul M. Weaver (2014) Green composites: A review of material attributes and complementary Applications, *Composites: Part A* 56 (2014) 280–289
- [9]. Saba N., M.T. Paridah, M. Jawaid (2015) Mechanical properties of kenaf fibre reinforced polymer composite: A review, *Construction and Building Materials* 76 (2015) 87–96
- [10]. Kabir M.M., H. Wang, K.T. Lau, F. Cardona (2013) Tensile properties of chemically treated hemp fibres as reinforcement for composites, *Composites: Part B* 53 (2013) 362–368
- [11]. Dhahi, T. S., Hashim, U., & Ahmed, N. M. (2011). Fabrication and Characterization of 50 nm Silicon Nano-Gap Structures. *Science of Advanced Materials*, 3(2), 233–238. <https://doi.org/10.1166/sam.2011.1155>
- [12]. Dielacher, B. K. (2015). A Combined Electrical, Plasmonic and Fluidic Measurement System for Metal Nanostructure based Ion Sensing, (22493). <https://doi.org/10.3929/ethz-a-010414691>
- [13]. Eshkeiti, A., Narakathu, B. B., Reddy, A. S. G., Rebrosova, E., Rebroso, M., Joyce, M., & Atashbar, M. Z. (2012). A Novel Fully Gravure Printed Flexible Surface Enhanced Raman Spectroscopy (SERS) Substrate for the Detection of Toxic Heavy Metals, 1479–1482. h
- [14]. Mohammad Razif Bin Mustafa, Tijjani Adam, U. Hashi, N. Azizah (2017) Specific and Selective Target Detection of Supra-genome 21 Mers Salmonella via Silicon Nanowires Biosensor, IConGDM2017-177, AIP Conference Proceedings ISSN: 1551-7616
- [15]. B. Basri, Tijjani Adam and U. Hashim (2017) Synthesis of zinc oxide thin films prepared by sol-gel for specific bioactivity, IConGDM2017-178, AIP Conference Proceedings ISSN: 1551-7616
- [16]. Mohammed Mohammed A.R Rozyanty Tijjani Adam, Bashir O. Betar (2017) Study of the Weathering Effect in a Natural Environment on the Hybrid Kenaf Bast /Glass Fibre-Filled Unsaturated Polyester Composite, ConGDM2017-181, AIP Conference Proceedings ISSN: 1551-7616
- [17]. Neesyan A/L David Rajah, Tijjani Adam Uda Hashim (2017) Lattices Parameter Dependent Of Effective Atomic Interactive Coefficient For Unstressed And Stressed 1nm Nanostructure, ConGDM2017-198, AIP Conference Proceedings ISSN: 1551-7616
- [18]. Mohamed Jamal Bin Amanullah, Tijjani Adam, Uda Hashim, (2017) Calculation of the Band Structure Parameter in Silicon Nanowires Using first Principle Analytical Method, AIP Conference Proceedings ISSN: 1551-7616
- [19]. Mohammed Mohammed A.R Rozyanty, Tijjani Adam, Bashir O. Betar (2017) ZnO Characterization, UV and Photocatalysis Mechanism for Water Repellent Phenomena in Polymer Poly Composite, IConGDM2017-211, AIP Conference Proceedings ISSN: 1551-7616

- [20]. Shillan A/L Bathmanathan, Tijjani Adam, Uda Hashim (2017) Optimization and Validation of Highly Selective Microfluidic Integrated Silicon Nanowire Chemical Sensor, IConGDM2017-212, AIP Conference Proceedings ISSN: 1551-7616
- [21]. G. Ozin, A. Arsenault, L. C. (2009). Nano chemistry, 0–3. Guo, Z., Seol, M., Gao, C., Kim, M., Ahn, J., Choi, Y., & Huang, X. (2016). Electrochimica Acta Functionalized porous Si nanowires for selective and simultaneous electrochemical detection of Cd ( II ) and Pb ( II ) ions. *Electrochimica Acta*, 211, 998–1005. <https://doi.org/10.1016/j.electacta.2016.06.141>
- [22]. Harrison, B. S. (2008). Applications of Nanotechnology. In *Principles of Regenerative Medicine* (pp. 554–561). <https://doi.org/10.1016/B978-012369410-2.50033-4>
- [23]. Joyner, J. J., & V., D. K. (2015). Nanosensors and Their Applications in Food Analysis: A Review. *International Journal Of Science & Technoledge*, 3(4), 80–90.
- [24]. Korent Urek, Š., Frančič, N., Turel, M., & Lobnik, A. (2013). Sensing heavy metals using mesoporous-based optical chemical sensors. *Journal of Nanomaterials*, 2013. <https://doi.org/10.1155/2013/501320>
- [25]. Li, Z., Chen, J., Guo, H., Fan, X., Wen, Z., Yeh, M. H., ... Wang, Z. L. (2016). Triboelectrification-Enabled Self-Powered Detection and Removal of Heavy Metal Ions in Wastewater. *Adv Mater*, 2983–2991. <https://doi.org/10.1002/adma.201504356>
- [26]. Long, F., Zhu, A., & Shi, H. (2013). Recent advances in optical biosensors for environmental monitoring and early warning. *Sensors (Basel, Switzerland)*, 13(10), 13928–13948. <https://doi.org/10.3390/s131013928>
- [27]. Luo, L., Jie, J., Zhang, W., He, Z., Wang, J., Yuan, G., ... Lee, S. T. (2009). Silicon nanowire sensors for Hg<sub>2</sub><sup>+</sup> and Cd<sub>2</sub><sup>+</sup> ions. *Applied Physics Letters*, 94(19). <https://doi.org/10.1063/1.3120281>
- [28]. Ly, N. H., & Joo, S. W. (2015). Silver nanoparticle-enhanced resonance raman sensor of chromium(iii) in seawater samples. *Sensors (Switzerland)*, 15(5), 10088–10099. <https://doi.org/10.3390/s150510088>
- [29]. March, G., Nguyen, T., & Piro, B. (2015). Modified Electrodes Used for Electrochemical Detection of Metal Ions in Environmental Analysis. *Biosensors*, 5(2), 241–275. <https://doi.org/10.3390/bios5020241>
- [30]. Melde, B. J., Johnson, B. J., & Charles, P. T. (2008). Mesoporous Silicate Materials in Sensing. *Sensors*, 8(8), 5202–5228. <https://doi.org/10.3390/s8085202>
- [31]. Park, W., Zheng, G., Jiang, X., Tian, B., & Lieber, C. M. (2008). Controlled synthesis of millimeter-long silicon nanowires with uniform electronic properties. *Nano Letters*, 8(9), 3004–3009. <https://doi.org/10.1021/nl802063q>
- [32]. Paul, B., & Tiwari, A. (2015). A Brief Review on the Application of Gold Nanoparticles as Sensors in Multi Dimensional Aspects, 1–7.
- [33]. Screen, S. N., & Carbon, P. (2016). Sensory Measurement of Mercury and Cadmium Ions in Water Using, 28(7), 1429–1434.
- [34]. Tarasov, A. (2012). Silicon Nanowire FET for Sensing Applications. *Thesis*.
- [35]. Tsang, C. H. a, Liu, Y., Kang, Z., Ma, D. D. D., Wong, N.-B., & Lee, S.-T. (2009). Metal (Cu, Au)-modified silicon nanowires for high-selectivity solvent-free hydrocarbon oxidation in air. *Chemical Communications (Cambridge, England)*, (39), 5829–31. <https://doi.org/10.1039/b912341e>
- [36]. Wang, C., & Yu, C. (2013). Detection of chemical pollutants in water using gold nanoparticles as sensors: A review. *Reviews in Analytical Chemistry*, 32(1), 1–14. <https://doi.org/10.1515/revac-2012-0023>
- [37]. Yang, S. I. (n.d.). Nanomaterial based Environmental Sensing What is Nanotechnology ?
- [38]. Zeng, S., Yong, K.-T., Roy, I., Dinh, X.-Q., Yu, X., & Luan, F. (2011). AuNP138-A Review on Functionalized Gold Nanoparticles for Biosensing Applications. *Plasmonics*, 6(3), 491–506. <https://doi.org/10.1007/s11468-011-9228-1>
- [39]. Zhang, L., & Fang, M. (2010). Nanomaterials in pollution trace detection and environmental improvement. *Nano Today*. Elsevier Ltd. <https://doi.org/10.1016/j.nantod.2010.03.002>



- [40].Tijjani Adam U. Hashim and Th S. Dhahi, Silicon nanowire formed via shallow anisotropic etching, Si-ash-trimming for specific DNA and electrochemical detection, Chinese Physics B Vol. 24, No. 6 (2015) 06810
- [41].Tijjani Adam, U Hashim, Design and fabrication of micro-mixer with short turns angles for self-generated turbulent structures, Microsystem Technologies, 1-8, 2015
- [42].T Adam, U Hashim, TS Dhahi, KN Khor, PS Chee, PL Leow, ELECTROCHEMICAL ETCHING: An Ultrasonic Enhance Method of Silicon Nano Porous Fabrication, Wulfenia Journal 20 (1), 45-55, 2013
- [43].Tijjani Adam, H Uda, M Equb, PL Leow, The electroosmosis mechanism for fluid delivery in PDMS multi-layer microchannels, American Scientific Publishers All rights reserved.2013
- [44].U Hashim, T Adam, J Lung, P Ling, Fabrication of Microchannel and Micro Chamber for Microfluidic Lab-on-Chip.Australian Journal of Basic & Applied Sciences 7 (1)2013
- [45].T Adam and U. Hashim Light Observation in Polymer: A Study of Silicon-Based Organic Polymer Using Visible Spectroscopy, Australian Journal of Basic and Applied Sciences 7 (1), 76-80, 2013.
- [46].U Hashim, MW Al-Mufti, T Adam, Silicon Nanowire Geometry: Investigation of Interaction Site Potential in Semiconductor-DNA Interaction, Australian Journal of Basic and Applied Sciences 7 (5), 242-245, 2013
- [47].MW Al-Mufti, U Hashim, T Adam, Simulation of Nano lab on chip devices by using COMSOL MultiphysicsJournal of Applied Sciences Research 9 (2), 1056-1061, 2013
- [48].T Adam, U Hashim, KL Foo, TS Dhahi, T Nazwa, Technology development for nano structure formation: Fabrication and characterization, Advanced Science Letters 19 (1), 132-137, 2013
- [49].T Adam, U Hashim, PL Leow, KL Foo, PS Chee, Selection of optimal parameters in fabrication of poly (dimethylsiloxane) microfluidics using taguchi method, Advanced Science Letters 19 (1), 32-36,2013
- [50].T Adam, U Hashim, KL Foo, Microfluidics design and fabrication for life sciences application, Advanced Science Letters 19 (1), 48-53, 2013
- [51].T Adam, U Hashim, ME Ali, PL Leow, The electroosmosis mechanism for fluid delivery in PDMS multi-layer microchannel, Advanced Science Letters 19 (1), 12-15, 2013