Mechanical Properties of Compression Molded Epoxy Polymer Composites Reinforced with Kenaf Fibers

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ABSTRACT

Kenaf composites have been widely used in the engineering and industrial applications such as air cleaner, dashboard, insulation mats, and fibreboard. Due to considerable attentions; kenaf fibres are reinforced in polymers for the fabrication of polymer composites. This work deals with the fabrication and characterizations of untreated and treated temafa kenaf fibres. The microstructure (SEM), flexural properties and tensile properties of the prepared kenaf polymer composites were discussed throughout this study. The kenaf fibres were treated with 6 wt% sodium hydroxide, NaOH solution for 24 hours soaking time. The epoxy thermoset reinforced with randomly oriented temafa kenaf was fabricated using compression molding technique. The composite samples of kenaf were prepared with different kenaf fibre loadings; 20 wt%, 30 wt%, 40 wt%, 50 wt% and 60 wt% . It was found that the properties of kenaf composites mainly depend on the compositions of kenaf fibres. It has also been investigated that the treatment influences the properties of kenaf itself. Overall, the results revealed that the treated kenaf composites have better mechanical properties such as flexural strength as compared to the untreated kenaf composites. However, it is observed that the flexural strength also increased with increasing percentage loading of kenaf fibres. These

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prepared kenaf composites will perform better mechanical properties than existing polymer may be used in automotive applications.

Keywords*: Kenaf Thermoset Composite, Material Processing, Flexural Strength, Tensile Strength, Microstructure.*

Introduction

The interest of using renewable and biodegradable natural fibres as reinforcement materials in polymer composites has increased in industries and academic field [1, 2]. The increment in using natural fibres is to replace the conventional synthetic or man-made fibres; Kevlar, glass, carbon and etc. This because natural fibres are environmental friendly, economical and beneficial to health. As compared to synthetic fibre, natural fibre has many advantages such as low density, reduce cost and easily available in most countries. Furthermore, they are less abrasive in tooling processing, less irritating to the human respiratory system and good thermal properties. These advantages have created interest to form the lightweight composite especially in automotive and aerospace industries in order for environmental friendly and save fuel.

In recent years, numerous natural fibres have been utilized in polymer composite fabrication such as jute, flax, pineapple, etc. Among these natural fibres, kenaf fibres are used as a reinforcement materials [3]. Historically, the kenaf fibres have been incorporated in various applications; constructions, automotive, building, etc. In recent years kenaf fibres have been extensively accepted in automotive industries for fabrication of interior and engine part such as headliner, dashboard, air cleaner and door trim [4]. This is because kenaf fibre have interesting mechanical properties in flexural and tensile strength. Generally, kenaf plant consists of inner woody core and outer bast surrounding the core. The kenaf plant shown in Figure 1 contain 35 – 40 % bast fiber and 60 – 65 % core fiber [5]. In contrast to core fibre, bast fibre is comprehensively used in composite materials production; thermoset and thermoplastic matrices. This is because kenaf bast fibre consists high cellulose content which can affect physical and mechanical properties. This finding was supported with other work by Ishak et al. [4]. The most popular thermoset and thermoplastic polymer used in kenaf fibres fabrication is polypropylene, thermoplastic urethane, epoxy, polyurethane and polyester. In this work, epoxy resin was used as a matrix to bond the fiber together and to transfer load between them [6].

Although kenaf fibres have many advantages, as previously mentioned, a serious problem with kenaf fibre is there are difficulties in mixing kenaf and polymer. This is because kenaf has a strong polar character (hydrophilic) which can lead to incompability with most polymer matrices (hydrophobic) [7].

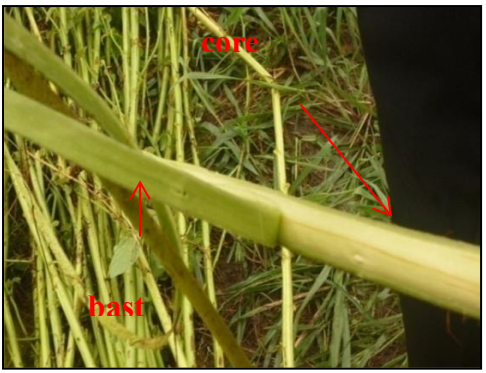


Figure 1: Kenaf plant.

Therefore, a chemical treatment is required for the kenaf fibres in order to increase the wetting of fibres with polymer matric [8]. It is well known that chemical treatment has successfully improved fibre strength and adhesion between matrices and fibres. Basically, chemical treatment removes lignin, hemicellulose, wax and oils covering the fibre surface which leads to better adhesion between fibre and polymer. Various chemical treatments were tested on natural fibres. From previous work, several researchers reported on the properties of kenaf composites when treated with alkali treatment at different concentrations and conditions. Meon et al. conduct mechanical properties of treated kenaf fibres composites with different concentrations; 3%, 6% and 9% in weight percent [9]. They found that 6wt% of NaOH had good tensile properties. This was also supported by Edeerozey et al., where they found that at 6 wt% concentration all impurities were removed from the SEM micrograph [10]. Therefore, in this work 6 wt% concentration of NaOH was selected as the chemical treatment due to its effectiveness in cleaning the fibre surface [11]. The aim of this work is to investigate effect of treated and untreated kenaf fibre on the mechanical and physical properties of kenaf/epoxy polymer composite reinforced at different kenaf fibre loading.

Experimental Procedure

Materials

Polymer composites materials were prepared using epoxy resin and *temafa* kenaf fibres. Epoxy (D.E.R^{TM} 331^{TM}) resin as matrix and curing agent was provided by the Dow Chemical Company. This epoxy come together with a hardener (JOINTMINE^{TM} 925-3S^{TM}) for the fast curing process. The discontinuous long temafa kenaf fibres, were supplied by *Lembaga Kenaf & Tembakau Negara* (LKTN), Malaysia. The mechanical properties of the epoxy provided in term of MSDS were summarized in Table 1.

Table 1: Characteristics of resin epoxy, D.E.R™ 331™ [MSDS sheet]

Properties	Value
Flexural Strength (N/mm^2)	96
Flexural Modulus (kN/mm^2)	3.0
Yield Compressive Strength (N/mm^2)	112
Tensile Strength (N/mm^2)	79
Elongation at Break (%)	4.4
Gel point time (min) 500g	25

Sample Preparation

Firstly, kenaf temafa fibres of density 1.71 g/cm^3 and diameter in between 45 to 250 µm were cleaned to separate excessive core. Prior to composite preparation process, alkali treatment process was carried out. Sodium hydroxide (NaOH), MERCK was used for the alkali treatment process with a concentration 6 wt%. The kenaf fibre swere soaked in NaOH solution for 24 hours under room temperature. Then, the fibres were immersed in tap water containing 1 wt% of acetic acid glacial (EMSURE) to neutralize the excessive NaOH. After that, the fibres were soaked for 30 minutes in distilled water followed by washing with distilled water until the pH 7. Then, fibers were dried under oven environment at 40 °C for 24 hours.

Compression molding process was used for the fabrication of epoxy reinforced with *temafa* kenaf fibres. The composites have size 100 mm x 100 mm and thickness ±3 mm with different percentage of temafa kenaf. Six different percentages of kenaf were 0 wt%, 20 wt%, 30 wt%, 40 wt%, 50 wt% and 60 wt% in weight were produced from the hardened steel mold. Figure 2 shows the methodology process flow for kenaf/epoxy composite. Figure 3 shows the sample preparations starting from kenaf fibres until kenaf compression molded composite. Firstly, the untreated (UT) and treated (T) fibers need to be pressed at 8 MPa for 5 minutes using compression molding machine for making the random oriented fibre mat [12]. Then, epoxy and hardener with ratio 2:1 were mixed using mechanical stirrer at speed rate 2 rpm for 5 minutes before cast into the mold with random oriented kenaf mat. These parameters were used in order to avoid bubble and also resin to become jelly. The mold was placed under compression molding environment for 15 minutes for the curing process. Then, the mold was pressed at 8 MPa of compression molding for 25 minutes [13]. Afterwards, the specimen was post cure for 20 minutes under room temperature after removed from the compression molding for the cooling process and kept in a dry cabinet in order to avoid from the humidity [8]. The fabricated composites were cut into rectangular shape with the dimension of 25 mm x 100 mm using a cutter blade for the characterizations process. During this work, six types of randomly oriented kenaf epoxy composites were fabricated with different fiber loading of epoxy and kenaf.

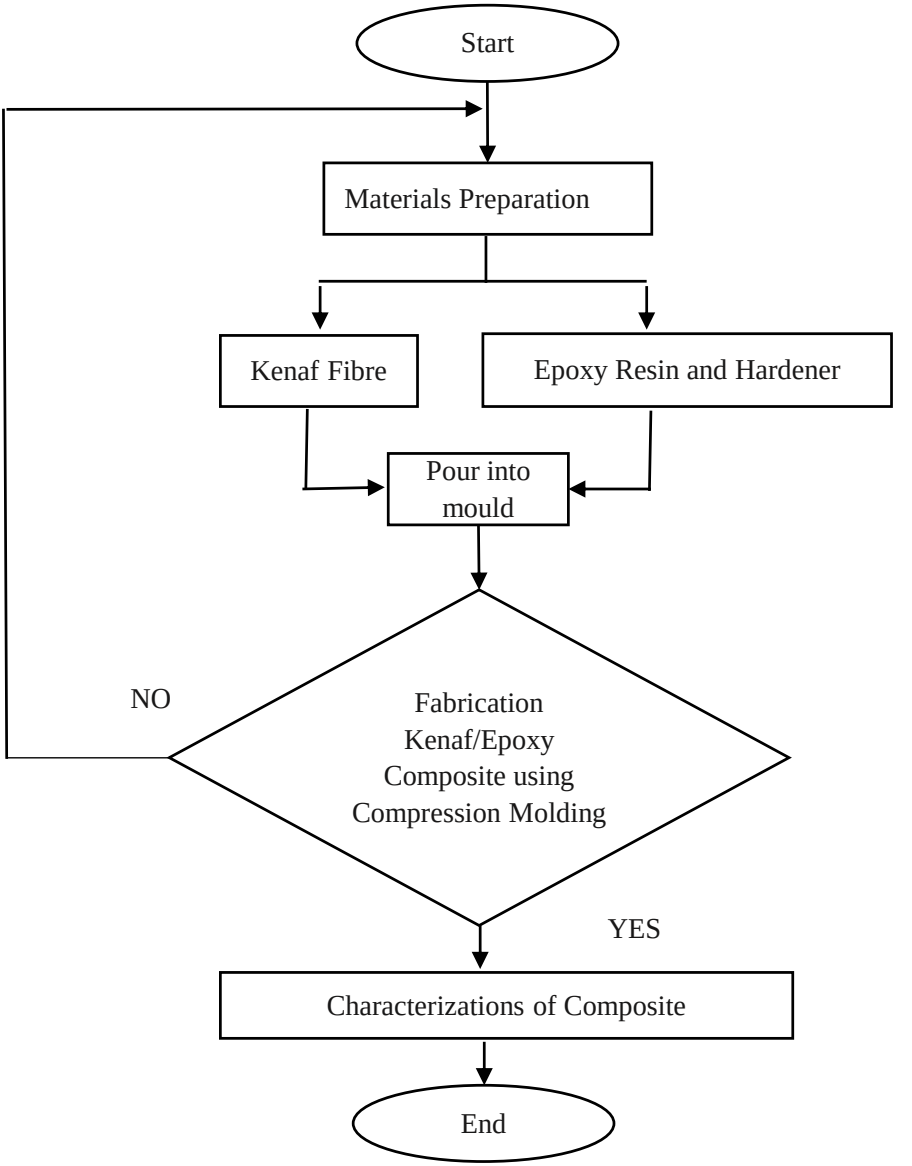
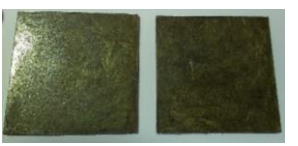


Figure 2: Methodology process

Kenaf fibre

(a) Untreated kenaf and (b) treated kenaf fibre in ramdomly mat shape



Compression molded kenaf composite

Figure 3:Compression molded kenaf composite

Properties Characterizations

Mechanical and microstructure kenaf composite were characterized by mechanical (flexural and tensile) and microstructure analysis. ASTM D790-99 standard was used to determine the flexural strength and flexural modulus. Testing was done under room temperature using universal testing machine (UTM), Model Instron 5567 with speed rate 2 mm/min and load cell 30kN.

The tensile strength and tensile modulus also were determined according to the American Society for Testing and Materials (ASTM D3039-14) standard using a universal testing machine (UTM), Model Instron 5567. A load cell 30kN was applied with a cross head speed of 2 mm/min. Four samples were tested under room temperature and average of the samples were calculated to get the average value.

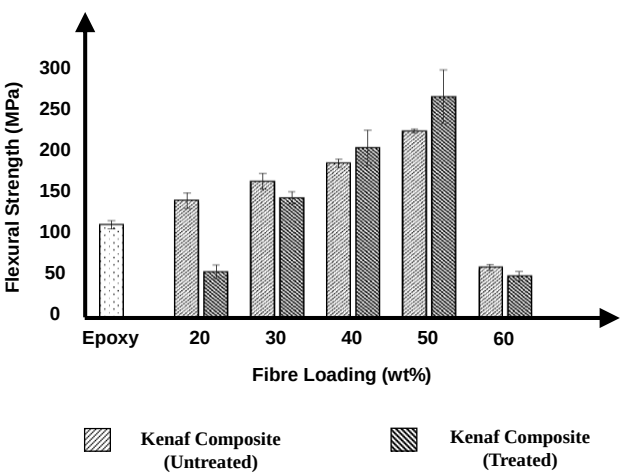
Scanning electron microscope, SEM (ZEISS) was used to examine the surface and cross section of the sample. The sample micrographs were observed by using a secondary scanning electron microscope at 100x magnification. Specimens were earlier coated with gold to increase their conductivity during the testing. SEM micrographs of the kenaf fibres before and after alkali treatment were also measured using scanning electron microscope.

Results and discussion

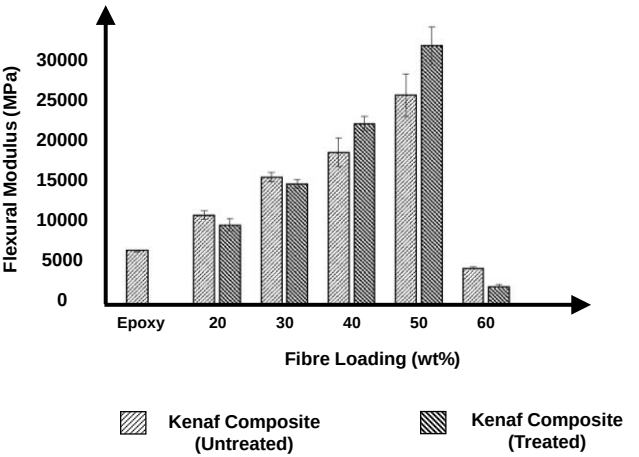
Mechanical characterizations

Flexural Properties

From the graph in Figure 4 (a), it is obvious that addition of kenaf fibres, either treated or not, gave superior flexural strength for the composite compre to pure epoxy polymer. Also, the same trend can be seen on the flexural modulus of composite after reinforced with kenaf fibre as shown in Figure 4 (b). The flexural strength and flexural modulus increased with increasing of kenaf loading for both types kenaf; untreated and treated. In this research, the weight percentage of fibre loading is increased up to 60 wt%. Based on the graph, the effect of the alkali treatment process can be clearly seen for both graphs in Figure 4. In this case, reinforcement treated kenaf of 20 wt % and 30 wt% fibre loading did not affect to the flexural strength and flexural modulus. Clearly shows that, the results for these fibre loading is lower than untreated kenaf fibre. This may be undesired treated kenaf at this fibre loading. However, reinforcement of 40 wt% and 50 wt% treated kenaf give higher flexural strength for both types of kenaf fibres. As illustrated in Figure 4 (a) and (b), the results obviously shows that optimum flexural strength and flexural modulus was obtained at 50 wt% fibre loading. The improvement flexural strength was about 98% and 135% and flexural modulus was 269% and 355% compare to pure epoxy polymer.



(a)

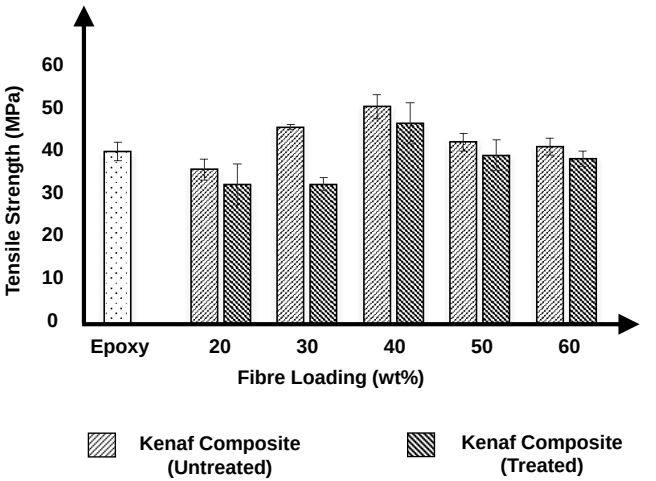


(b)

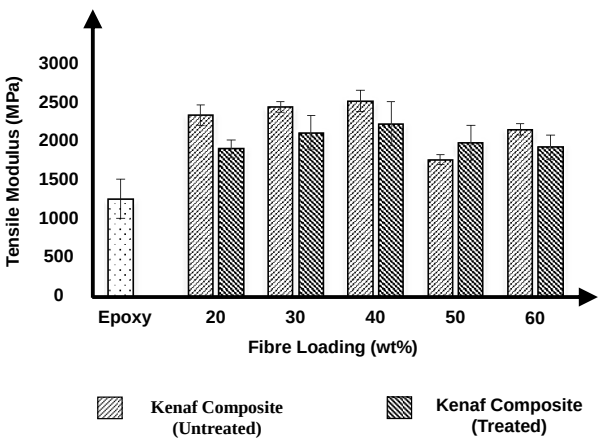
Figure 4: (a) Flexural strength and (b) flexural modulus of epoxy composite reinforced with untreated and treated kenaf fibre

Tensile Properties

Figure 5 (a) and (b) represent the tensile properties of the epoxy composite reinforced with untreated and treated kenaf fibres. All the composite reinforced with the untreated kenaf showed higher tensile properties than the treated kenaf fibres. Generally, reinforcement of the fibres increase the tensile strength and modulus because the fibre has higher strength and stiffness compare to the matrix [14]. However, it slightly showed a difference in this work wherein reinforcement of 20 wt % of untreated and treated produced lower tensile strength. From the result, it was clearly shown that addition of 40 wt% of untreated and treated kenaf loading produced higher tensile strength and tensile modulus. This results are in agreement with the result obtained from previous research [8]. They revealed that 40 wt% of fibre loading produced higher tensile strength. However, the tensile strength of epoxy reinforced with 50 wt% for both type of kenaf fibres decreased to 41 MPa and 36 MPa. The same trend in decrease can also be seen in the tensile modulus by reinforcing with 50 wt% (untreated and treated) loading where the value decreased to 2282 MPa and 2039 MPa. Figure 5 (a) and (b) clearly indicated that optimum tensile strength and tensile modulus was obtained at 40 wt% fibre loading. The improvement tensile strength was about 25% and 15% and tensile modulus was 94% and 73% compare to pure epoxy polymer.



(a)



(b)

Figure 5: (a) Tensile strength and (b) tensile modulus for epoxy composite reinforced with untreated and treated kenaf fibre

SEM Analysis

Surface analysis of untreated and treated kenaf fibres

SEM analysis was carried out on the fibres to see changes before and after alkali treatment. This analysis was performed on the kenaf fibre bundles. It clearly showed that untreated kenaf in Figure 6 (a) had layer of impurities, wax

and oils present. While, the SEM micrograph of the fibres bundle treated with NaOH showed a clean surface (Figure 6 (b)). Furthermore, the surface was smooth with fine structure. This result is agreement with the previous work done by a group of mentioned that the alkali treatment can modify the fibres surface [15].

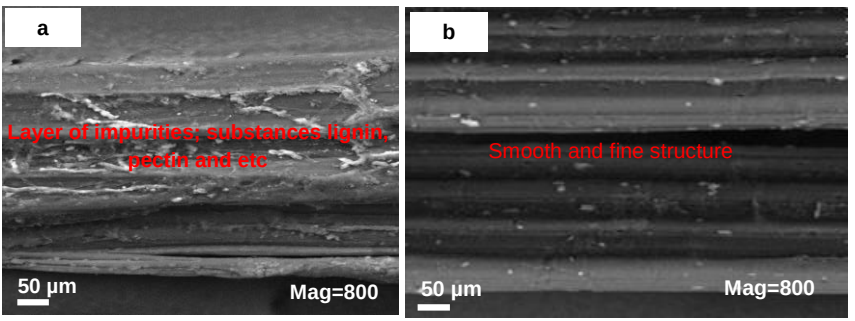


Figure 6: Surface analysis for (a) untreated kenaf fibres and (b) treated kenaf fibres.

Morphology of flexural surfaces

In this section, the distribution and bonding of untreated and treated kenaf fibres were observed and analyzed after running the flexural analysis. SEM observation was illustrated in Figure 7 (a) and (b). Based on SEM image, comparison of the results obtained from untreated and treated kenaf showed different distribution of fibres. This obviously showed that epoxy resin was not able to enter the untreated kenaf fibre. Generally, the epoxy resin was not distributed evenly and caused the increment of porosity and kenaf fibres do not bond well with the epoxy resin. Basically, the increment of porosity leads to a decrease in the mechanical properties of composite.

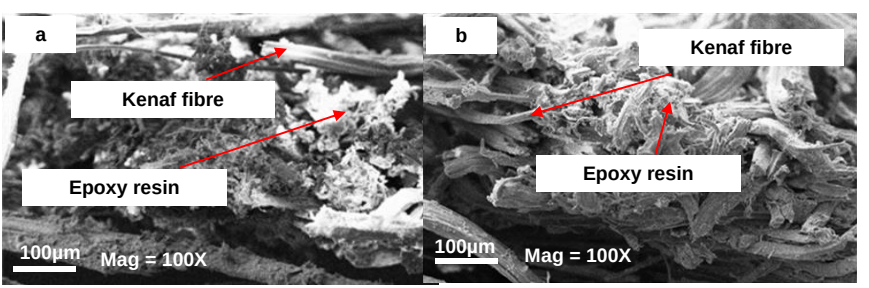


Figure 7: SEM observation of bonding between (a) untreated kenaf fibre and epoxy resin and (b) treated kenaf fibre and epoxy resin.

Conclusion

In conclusion, a process for fabrication of randomly oriented discontinuous long fibre composite was successfully developed. Based on SEM, interfacial bonding strength was not high and there were voids on the cross section. The results also indicated that alkali treatment and fibre loading of the natural fibre highly influence the mechanical properties of epoxy composite reinforced with kenaf fibres. From the SEM image, the epoxy composite reinforced with treated kenaf has a better microstructure because the epoxy can enter the kenaf. The discussion on the flexural properties proved that the increment of fibre loading will increase flexural strength and flexural modulus of composite. But, low mechanical properties from tensile test as compared to untreated kenaf composite. The tensile strength and tensile modulus achieved a maximum result at the 40 wt% of fibre loading for both type of kenaf. For the future work, an experiment design need to be applied for various fibre loading and processing parameter with regards to get the optimum processing parameter with high mechanical properties.

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References

[1] C. W. Nguong, S. N. B. Lee, and D. Sujan, "A Review on Natural Fibre Reinforced Polymer Composites," International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering 3 73, 1123–1130 (2013).

[2] A.K. Mohanty, M. Misra and L.T. Drzal, "Natural Fibers, Biopolymers, and Biocomposites," (Taylor & Francis Group 2005).

[3] B.F. Yousif, A. Shalwan, C. W. Chin and K.C.Ming, "Flexural properties of treated and untreated kenaf/epoxy composites," *Materials and Design* 40, 378-385 (2010).

[4] M.R. Ishak, Z. Leman, S. M. Sapuan, A.M.M. Edeerozey, and I. S. Othman, "Mechanical properties of kenaf bast and core fibre reinforced unsaturated polyester composites," *IOP Conf. Ser. Mater. Sci. Eng.*, 11,12006 (2010).

[5] H. P. S. A. Khalil, A. F. I. Yusra, A. H. Bhat, and M. Jawaid, "Cell wall ultrastructure , anatomy , lignin distribution , and chemical composition

of Malaysian cultivated kenaf fiber," Journal of Industrial Crops and Products 31,113–121 (2010).

[6] B. F. Yousif, A. Shalwan, C. W. Chin, and K. C. Ming, "Flexural properties of treated and untreated kenaf / epoxy composites," Journal of Material and Design, 40, 378–385(2012).

[7] R. Mahjoub, J. Mohamad, A. Rahman, M. Sam, and S. Hamid, "Tensile properties of kenaf fiber due to various conditions of chemical fiber surface modifications," Journal of Constrion Building Material,55,103–113 (2014).

[8] N. A. Ibrahim, K. A. Hadithon, and K. Abdan, "Effect of Fiber Treatment on Mechanical Properties of Kenaf Fiber-Ecoflex Composites," Journal of Reinforced Plastic. Composites 29 (14), 2192–2198,(2010).

[9] M. S. Meon, M. F. Othman, H. Husain, M. F. Remeli and M. S. M. Syawal, "Improving Tensile Properties of Kenaf Fibers Treated with Sodium Hydroxide," Journal of International Symposium on Robotics and Intelligent Sensors 41,1587–1592,(2012).

[10] A. M. M. Edeerozey, H. M. Akil, a. B. Azhar and M. I. Z. Ariffin, "Chemical modification of kenaf fibers," Journal of Material Letters 61(10), 2023–2025 (2007).

[11] Z. N. Azwa and B. F. Yousif, "Characteristics of kenaf fibre/epoxy composites subjected to thermal degradation," Journal of Polymer Degradation and Stability 98(12), 2752–2759,(2013).

[12] H. P. S. A. Khalil and N. L. Suraya, "Anhydride modification cultivated kenaf bast fiber modifications: morphological, spectroscopic and thermal studies. Journal of Bioresources,"6,1122–1135 (2011).

[13] A. Bakar, "Effect of Epoxidized Natural Rubber on Mechanical Properties of Epoxy Reinforced Kenaf Fibre Composites," Journal of Science & Technology 20, 129–137, (2012).

[14] M. Sumaila, I. Amber and M. Bawa, "Effect of fiber length on the physical and mechanical properties of random oreinted , nonwoven short banana (musa balbisiana) fibre / epoxy composite," Asian Journal of Natural & Applied Sciences 2(1), 39–49, (2013).

[15] S. H. Aziz and M. P. Ansell, "The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1 – polyester resin matrix," Journal of Composites. Science and. Technology. 64(9),1219–1230 (2004).