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Kenaf Fibre and Its Bio-Based Composites: A Conspectus

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ABSTRACT

Kenaf fibre is a good reinforcement in fibre polymer composites due to its high strength and elastic modulus, high stiffness, low density, low cost and eco-efficient, less health hazards, renewability, good mechanical and thermal properties, and biodegradability. It is traditionally used for rope, twine, fish net and sacking materials. Recently, it was observed that kenaf fibre had huge potentials to replacing synthetic fibre in composites due to the rising environmental and ecological issues, thus this awareness has motivated efforts for the advancement of new innovative bio-based composites incorporating kenaf fibre for various end-use structural applications. This paper presents an overview of the development made so far in the area of kenaf fibre and its composites in terms of chemical and micro-structural properties, mechanical properties, dimensional stability, thermal stability, product development and application. Some fundamental issues and suggestions for further research in this area are also discussed.

Keywords: Kenaf fibre, mechanical properties, natural fibre, polymer composite, surface treatment, thermal properties

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INTRODUCTION

Kenaf fibres embedded in polymer matrices bring great benefits to diverse industries, natural environment, advanced technological sectors and end-users alike because of the depletion of petroleum resources (Nashino et al., 2003; Ochi, 2008; Wambua et al., 2003). The shift to more sustainable constructions for civil

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infrastructure is not only an initiative towards a more viable environment and cost efficiency but also a demand from the world environmental and ecological regulatory bodies. To this end, the engineers and scientists have presented green composites made from renewable agricultural materials as suitable alternative to synthetic fibre reinforced composites (Fiore et al., 2015).

In addition to the environmental and economic issues poised with the used of synthetic fibres in polymeric composites, natural fibre composites have several other advantages as substitute to synthetic fibre in composites such as recyclability, renewability, biodegradability, abundant, resistance to corrosion, non-toxicity, high flexibility, competitive mechanical properties, low density, less energy consumption, minimum abrasive resistance to processing equipment and waste disposal problems (Ander et al., 2016; Hassan et al., 2017; Reza et al., 2014a; Zamri et al., 2016). The major drawback in the utilization of natural fibres in polymeric composites is that natural fibres usually contain huge amounts of the hydroxyl group which makes them polar in nature. The addition of hydrophilic natural fibres to hydrophobic polymer which is non-polar material will result to a poor mechanical and durability properties due to non-uniformity of the fibre dispersion within the polymer and poor compatibility between the fibre and the matrix, however, this issue can be addressed by chemical treatments (maleic anhydride, isocyanates, organosilanes, permanganate peroxide, sodium hydroxide) and physical treatments (corona treatment and cold plasma treatment) as reported by Wambua et al. (2003).

Among the several types of natural fibres, kenaf fibre has gained considerable attention and been largely utilized over the last two decades (Huda et al., 2008; Liu et al., 2007; Nashino et al., 2003; Vijayakumar et al., 2014). The rationale behind this acceptance is mainly due to the rapid growing abilities of kenaf plant which enables it to produce a great volume of raw materials in a short period of time and consequent low price (Abdul Hamid et al., 2009; Hossain et al., 2011; Seller & Reichert, 1999). Natural fibres such as kenaf fibres are far cheaper when compared with carbon fibre and glass fibre. The price of kenaf fibre per kg is 0.53 US$ as against glass fibre and carbon fibre which is 3.25 US$ and 500 US$ per kg respectively (Li et al., 2000; Mohanty et al., 2000). In addition, Principia partners (2003) observed that natural fibre sources were cost-effective alternatives comparatively speaking. In the USA price for instance, Free on Board (FOB) were mentioned in mid-2003, ranges between 0.23 US$ and 0.47 US$ per pound and 500 US$ and 1036 US$ per metric ton for kenaf, hemb, sisal and flax fibres of numerous grades. Nashion (2004) carried out a research and stated that it took more energy to produce glass fibre than what it took to produce kenaf fibre and it was put at 54 moles per joule to produce 1kg of glass fibre while kenaf fibre took only 15 moles per joule to produce the same quantity. Figure 1 shows cost comparison between some natural fibres and E-glass as presented by Thakur et al. (2014).

Wambua et al. (2003) had demonstrated that natural fibre polymer composites including kenaf fibre polymeric composites had been linked with mechanical properties that could measure up to or even better than glass fibre reinforced composites. Also, worthy of note is the weight reduction ability of kenaf fibre as alternative to synthetic fibres in composites as well as low impact on the environment. Kenaf also maintains a competitive price as against synthetic fibres which required a large amount of energy to produce.

Kenaf Plant

Kenaf according to Vision paper (2003) has been in existence for over 4,000 years with origin traced to ancient Africa. The kenaf plant belongs to the hibiscus family (*Hibiscus cannabinus* L.) which is closely related to the family of jute, cotton and okra, which is grown in India, Bangladesh, Malaysia, United State of America, Indonesia, Vietnam, Thailand, South Africa and other parts of Africa, and some specific parts of south-east Europe. In the United State of America, kenaf grows rapidly to a height of about 3.5 – 4.5m in a short period of time while in Malaysia, this plant grows to 1.5 – 3.5m tall within short period of time. Lately in Malaysia, for example kenaf was recognised as an important natural raw fibre capable of replacing tobacco in the manufacturing of many products in construction, automotive, textile and other technological sectors (Anuar & Zuraida, 2011; Raji, 2007; Srayya & Kumar, 2015; Vision paper, 2003; Webber et al., 2002a).

Rouison et al. (2004) elucidated that kenaf had been cultivated in recent years because of some reasons. Firstly, kenaf absorbs both phosphorus and nitrogen that are found in the soil. These minerals also aid the increase of cumulative weed weight, stem diameter, fibre yield and crop height (Kuchinda et al., 2001). It was further reviewed by Kuchinda et al. (2001) that nitrogen addition at 90kgN/ha had important effect for the growing of the plant. Finally, kenaf converts carbon-dioxide to oxygen at a notably higher rate. Furthermore, Nashino et al. (2003) affirmed that the photosynthesis of kenaf was higher than other conventional trees. Kenaf's photosynthesis rate is 23.4mg $CO_2/dm^2/h$ when likened to other conventional trees of 8.7mg $CO_2/dm^2/h$ under 1000µmol/cm^2/s (Lam & Liyam, 2000). This means that the kenaf plant is environmentally friendly not only in terms of its biodegradability but also produces good amount of oxygen and likewise reducing carbon-dioxide.

Morphology of Kenaf Plant

Kenaf is an herbaceous plant with strong fibrous stalk, which is not vulnerable to insect attack and requires moderately less or no pesticides for its growth (Elsaid et al., 2011). According to Akil et al. (2011), the kenaf stalk comprises two main components; the bast fibres and the core fibres. The bast fibres account for about 30-40% weight of the dry plant

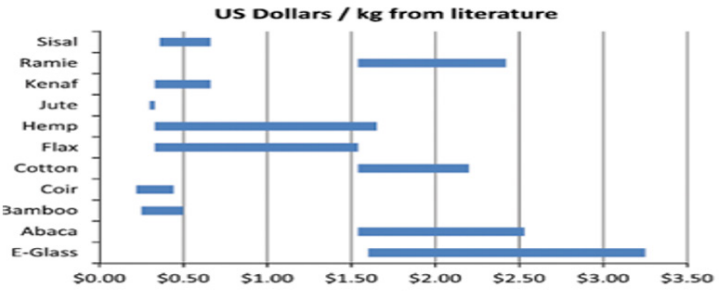

Figure 1. Cost comparison between natural fibres and E-glass (Thakur et al., 2014)

and form the outer-layer of the stalk. The bast fibre is made up of cellulose, hemicellulose and lignin with the value of (56-60%), (21-35%) and (8-15%) by weight respectively (Davoodi et al., 2010; Mazuki et al., 2011). The main attraction of the kenaf plant is the bast fibres because of their specific high strength to low density. The pectin, a natural binder found in the kenaf plant performs the function of holding the fibres to each other. Though the core fibres are not as strong as the bast fibres, but they provide the stack the necessary rigidity in bending. In a similar vein, Ashori et al. (2006) carried out a research on both the bast fibre and core fibre and concluded that fibres morphology showed that the kenaf bast fibres were slender and longer, though the core fibres were much wider and shorter. The morphology and chemical properties showed that the bast and core fibres were significantly different. Figure 2 shows the photo of kenaf plant, components of a typical stalk in cross-section showing the bast and core, kenaf bast fibre, and kenaf core fibre. Table 1 shows the chemical properties and compositions of a typical kenaf.

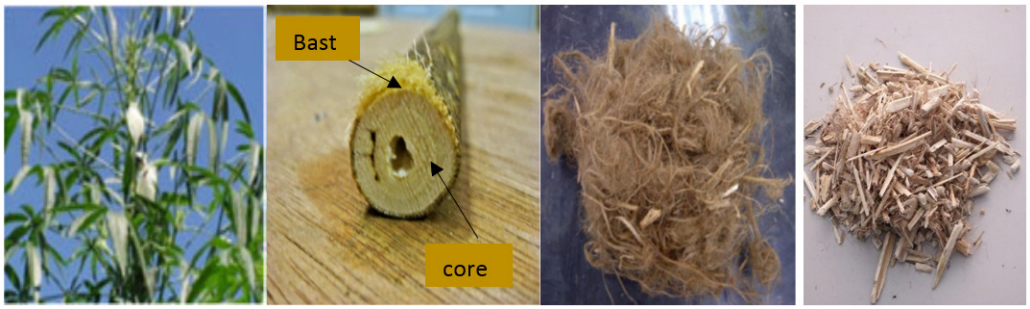

Figure 2. Kenaf plant, kenaf stalk and bast, and core fibres

Table 1

Chemical Properties and Compositions Kenaf in percentages (Ashori et al., 2006)

	Holo-cellulose	Cellulose	Hemi-cellulose	Lignin	Pentosan	E.B. Extract.	1% NaoH Extract.	Hot water	Ash
Bast	82.6	56.4	26.2	14.7	13.5	2.7	14.5	3.4	2.2
Whole	77.2	48.7	28.1	19.9	19	2.3	17.3	3.6	1.8
Core	75.8	46.1	29.7	22.1	20.7	2.2	20.6	3.9	1.6

Surface Modification of Kenaf fibre

The surface property is one main properties of natural fibres in the sense that it affects the interfacial bonding between the resin and the fibres surface and subsequently affects properties of the natural fibre composite in terms of physical and mechanical. All vegetable plant-derived from cellulose fibres including kenaf fibre are polar in nature, primarily due to their molecular and chemical structure (Ashori et al., 2006). Natural fibres comprise of non-cellulosic components like hemicelluloses, lignin and pectin, which hemicelluloses and pectin are hydrophilic. Hemicelluloses and pectin contain primarily functional group of hydroxyl and carboxylic structures which are vulnerable to water absorption. The cellulose constituent also contains reasonable hydroxyl groups, because minimal water may be accumulated within the extremely ordered and thoroughly crystalline microfibrils (Wambua et al., 2003). However, natural fibre pre-treatment will chemically clean up the surface, halt the absorption of moisture and increases the roughness on fibre surface. The fibre surface is usually influenced by the morphology of polymer, extractive chemical and processing condition. The degree of the interface of the matrix is paramount for applying plant fibres as reinforcement in polymer resin (Dissanayake et al., 2010; Sreekala et al., 2000). The two methods used to optimize plant fibres surface are discussed below.

Physical Modification of Kenaf Fibre. Reinforcing natural fibre can be changed by physical methods and techniques, for example, thermo-treatment, calendaring, stretching, and generation of quality hybrid yarns. These techniques don't change the chemical composition of the filaments yet anyway they change the structural and surface properties of the fibre. Physical treatments alter the morphological properties of natural vegetable fibres without the utilization of chemical agents, thus increasing the mechanical adhesion of fibres and polymer. Corona, cold plasma and heat treatments are other forms of physical treatments. Physical treatments are used to modify either the fibre or polymer matrix. (Dissanayake et al. 2010; Sreekala et al., 2000).

Corona technique exploits the corona effect which involves the fibrillation of the fibre/filler surface through the development of high electromagnetic fields energy near to charged tiny lines or points thus ensuing ionization in within the closeness, at atmospheric pressure and comparatively moderate temperature. In the ionized area, thrilled species (ions and radicals) are found to be present, subsequently become active during the surface treatment, through the introduction of functional groups containing oxygen. In addition, prolong time for treatment may give rise to fibre with noticeable rough surface (Garbassi et al., 1994). Corona treatment is a most standout amongst the most intriguing methods for fibre surface oxidation enactment. This technique modifies the surface vitality of the natural fibres, it boosts the volume of aldehyde groups. It also changes the surface energy of the cellulosic fibres, which in turn affects the melt viscosity of composites (Belgacem et al., 1994). Corona treatment has been successfully used in the modification of natural fibres such as jute, kenaf and flax fibres (Belgacem et al., 1994; Gassan & Gutowski, 2000; Salem et al., 2017).

Plasma treatment is another form of physical treatment similar to corona treatment which makes use of plasma property to modify the fibre surface. At the course of the treatment, an ionized region is formed with its composition depending on the gas fed, including high energy electrons, photons and radicals (Garbassi et al., 1994). Kalia et al. (2009) similarly reasoned that Plasma was generated by high voltage to modify the surface of cellulosic fibre for the purpose of increasing the surface energy or polarity, thus increasing the compatibility with polymer matrix. Electrical discharge is the easiest and commonest means to sustain a plasma for a long time. Plasma is believed to bring a physical change on the surface through roughening of the fibre by the sputtering effect, creating an enlargement of contact area that upsurges the friction between the fibre and polymer. In cold plasma, the electron temperature is 10-100 times higher than the low gas temperature (d'Agostina, 1990). However, due to low density and the low heat capacity of the electrons, the high temperature of electrons does not suggest that the plasma is hot. This is why cold plasma can be used in fibres surface treatment. The high electron temperature gives room to a sputtering effect on the fibres surface. The low gas temperature, being as low as room temperature in most cases permit fibres to experience such plasma surface modification without losing their mechanical properties (Xiao, 1997). Plasma treatment has been used for the treatment of coil fibre, jute fibre and many other natural fibres with satisfactory performance (Fariasa et al., 2017; Morshed et al., 2012).

Heat treatment encompasses heating the fibres to produce composites at a high temperature near to which the constituents of lignocellulose fibres start to degrade. When cellulose is subjected to elevated temperature, it experiences both chemical and physical changes. Physical properties that are likely affected for example weight, colour, strength, enthalpy and crystallinity. Chemical changes include creation of free radicals, reduction of

the degree of polymerization by bond scission, formation of carbonyl and peroxide groups (Shafizadeh, 1985). Chang et al. (2018) ascertained the mechanical and wear properties of heat treated pultruded kenaf fibre-reinforced polyester composites. The heat treatment temperatures were varied from 120^0C, 140^0C and 170^0C. The results showed that the heat-treated pultruded kenaf fibre composites with 140^0C heat treatment exhibited better wear performance than the untreated kenaf fibre composites and kenaf fibre composites treated with 120^0C and 170^0C heat temperatures. The flexural strength and modulus for all treated pultruded kenaf fibre composites increased after heat treatment. Ariawan et al. (2014) studied the effect of heating time during heat treatment on the mechanical and physical properties of kenaf fibre and its composites. Kenaf bast fibres were modified by constant heat temperature at 140^0C for 2.5, 5, 7.5, 10, and 12.5 hours. The researchers confirmed through XRD observation that the increase of cellulose content in kenaf fibres explained the increase of crystallinity index of kenaf fibre with heat treatment. The single fibre optimum strength and modulus was obtained when the kenaf fibre was heated for 10 hours. SEM images as showed in Figure 3 explains the decreasing numbers of impurities on the fibres surface with fibre treatment compared to the untreated kenaf fibres. Also, flexural properties of the composites showed a similar behaviour to the fibre strength.

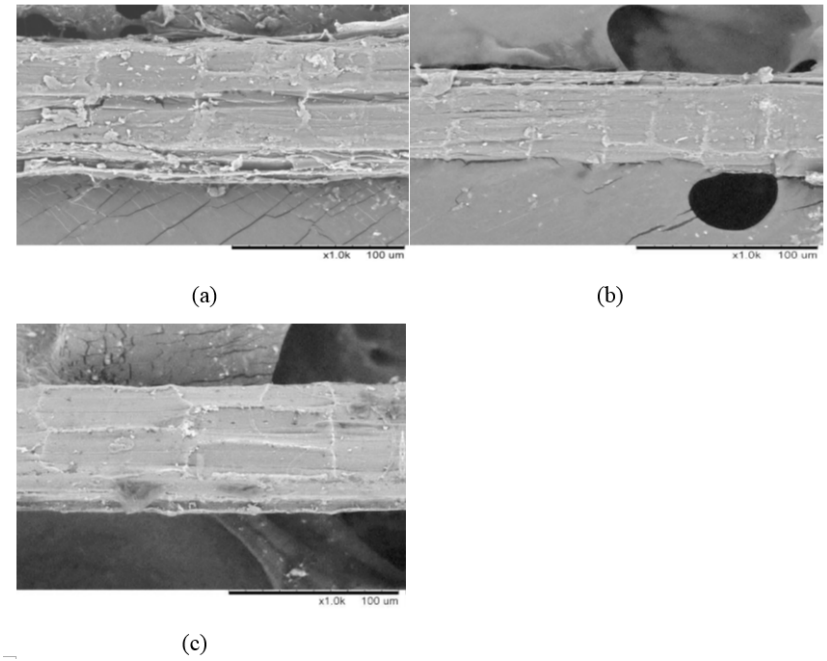

Figure 3. SEM images of heat treated kenaf fibre surface at (a) 0 hour, (b) 7.5 hours and (c) 12.5 hours of heating (Ariawan et al., 2014)

Chemical Modification of Kenaf Fibre. Chemical treatment uses chemical agents to alter the morphology of natural vegetable fibre. This is done through structural modification of the natural fibres or introducing new hydrophobic functional groups into the fibres surface to decrease the hydrophobicity of fibres. Several chemical treatments of natural fibres are being employed by numerous researchers to enhance the mechanical and durability properties of natural vegetable fibres including mercerization, oxidation, crosslinking, graft copolymerization, isocyanate treatment, acrylation, acetylation, permanganate peroxide treatment and silane coupling agent treatment (Dai & Fan, 2014; de Albquerque et al., 2000; George et al., 2001; Kalia et al., 2009 Mehta et al., Mwaikambo & Ansell, 2002; 2006; Ray et al., 2002a).

Mercerization of kenaf fibre. Mercerization also known as alkaline treatment is the commonest method used for the treatment of natural fibres which leads to good quality fibres. Alkaline solution prompts fibrillation which leads to fibres bundle breakdown into smaller units. Li et al. (2007) affirmed that this treatment removed hemicellulose, lignin, oil and wax covering the fibre surface. Mercerization decreases the fibre diameter, thus increases the feature which prompts the advancement of rough surface structure which gives better interfacial bonding between the fibre and matrix and further gives rise to superior mechanical and durability behaviour (Ray et al., 2002a). According to Joseph et al. (2000), alkaline treatment rises the number of likely reactive sites which allows better wetting. Alkaline treatment is among the most effective methods and at the same time cost-effective method for modification of natural vegetable fibre surfaces. The chemical reaction between NaOH and natural vegetable fibre (cell-OH) assumed to take place as presented in Equation 1:

$$\text{Fibre} - \text{OH} + \text{NaOH} - \text{Fibre} - \text{O}^{-}\text{Na}^{+} + \text{H}^{2}\text{O} + \text{surface impurities} \quad [1]$$

Mercerization of natural fibres. Meon et al. (2012) indicated that 6% of sodium hydroxide concentration delivered the best results on tensile properties of kenaf fibre. Kenaf fibres were soaked in 3%, 6% and 9% of sodium hydroxide concentration for one day and subsequently dried at 80^{O}C for the period of 24 hours. Similarly, Reza et al. (2014a) conducted a research on the mechanical behaviour of kenaf yarn fibre under several conditions of fibre modifications. The kenaf fibre used for the research were both treated and non-treated. The kenaf fibres were treated in 5%, 7%, 10% and 15% concentration of alkaline solution. It was reported that 5% of alkaline concentration gave the best result for the fibre treatment as a result of the minimal tension on the fibre surface and structure. Higher alkaline concentration at 10% and 15% was discouraged because according to the authors impaired the texture of fibres as treated fibres were seen most turned, more finer and so fragile as compared to the non-treated fibres and those treated with lower concentration of alkaline solution. Figure 4 showed the physical appearance of kenaf fibre after treatment.

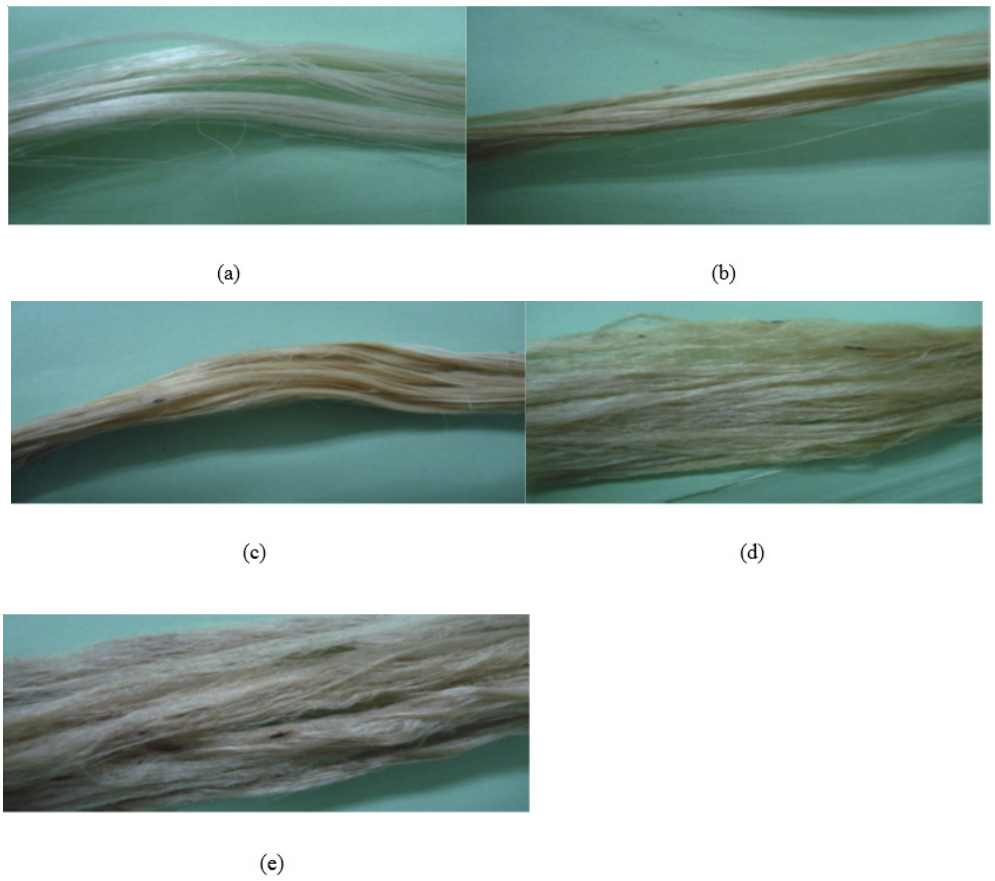

Figure 4. The physical appearance of kenaf fibre of untreated and after treatment (Reza et al. 2014a) (a) 3 hours immersion in 5% alkaline solution (b) 3 hours immersion in 10% alkaline solution (c) 3 hours immersion in 7% alkaline solution (d) 3 hours immersion in 15% alkaline solution

Several other scholars reported enhancement in mechanical behaviour of kenaf fibre when alkalized with different concentrations of sodium hydroxide. Aziz and Ansell (2004) carried out a research on the alkalization effects to the properties of hemp and kenaf bast fibres polymeric composites using 6% alkaline concentration for treating kenaf fibre and hemp fibre surfaces. It was found that the density of kenaf fibre and hemp fibre did not show a significant change after treatment with 6% alkaline concentration. However, the flexural strength of the polymer composites with the treated fibres has superior results in comparison with untreated composites. Dynamic mechanical analysis reviewed that the composites from treated fibres gave higher E^{I} values conforming to superior flexural moduli. Razak et al. (2014) conducted a research to enhance the interfacial adhesion and electronic behaviour of kenaf fibre/polyaniline bio-fibres. 6% weight of sodium hydroxide solution was used in treating the kenaf fibre and reported that the solution of sodium

hydroxide enhances the unit break of the tensile properties of the kenaf fibre owing to the elimination of impurities at the fibre surface which neutralises the hydroxyl group. It was concluded that all the treated kenaf fibres revealed higher mechanical strength than the untreated fibres. Edeerozey, Akil et al. (2007) studied the effect of chemical treatment on kenaf fibre using 3%, 6% and 9% sodium hydroxide solution. Series of fibre tests were done to assess the outcome of the treated fibre on the mechanical properties. The breaking strength was computed from the stress-strain curve and the unit break (UB) using equation 2 (Wang et al., 2003):

$$UB = F/d \quad [2]$$

Where

F = Maximum breaking load (N)

d = Cross-sectional area of fibre (mm^2)

It was found that surface treatment of kenaf fibre through alkalization had enhanced the mechanical properties significantly when compared with untreated fibre. The authors stated that 6% sodium hydroxide solution gave the optimum performance for treatment of kenaf fibre (Edeerozey et al., 2007). Farahani, Ahmad and Mosadeghza (2012) carried out a research on alkaline treatment and its effect on the mechanical properties, densities and water absorption of kenaf fibre/polyester composites using 10% concentration of sodium hydroxide concentration for 3hours at ambient temperature. It was reported that alkaline treatment led to improved interfacial strength between fibre and the resin which enhanced all the properties of the polyester composites. The researchers reasoned that surface treatment lowered the absorption of water on the composites. Asumani, Reid and Paskaramoorthy (2012) demonstrated the effects of alkali-saline treatment on kenaf reinforced polypropylene composites. The kenaf bast fibre was grouped into three forms; treated with sodium hydroxide, untreated and treated with Sodium hydroxide and silane. Mechanical tests shown that alkali treatment took after by silane treatment essentially enhances the tensile property and flexural property of the composites. Furthermore, Mohd Yuhazri, Phongsakorn, Haeryip and Kannan (2012) carried out a study to ascertain the effects of alkaline treatment on the mechanical behaviour of kenaf/polyester composites using varying concentration of alkaline solution ranging from 3% to 9% as shown in (Figure 5). Figure 5(a) shows the SEM image of the untreated kenaf fibre. Impurities were visibly noticed on the untreated fibre surface. Figure 5(b) shows the image of the surface of kenaf fibre treated with 3% sodium hydroxide solution for 12hours from SEM. It was observed that the fibre was cleaner than the untreated fibre. Figure 5(d) shows the image of treated kenaf fibre using 6% of sodium hydroxide solution for 12 hours from SEM. It was noticed that most of the impurities were cleaned off from the fibre surface. The increasing immersion time as in the cases of Figure 5(c) and Figure 5(e) led to damage of the fibre surface as shown in the images from SEM. Figure 5(f) presents the image from SEM of

9% sodium hydroxide solution for 12 hours and have the cleanest the fibre surface. The research was concluded that alkaline treatment of kenaf fibre improved interfacial adhesion between the polyester resin and fibre which gave rise to superior mechanical properties.

Silane treatment of kenaf fibre. Silane is one of the essential components of the reactive species used for natural fibre treatment. The key group of coupling agents with

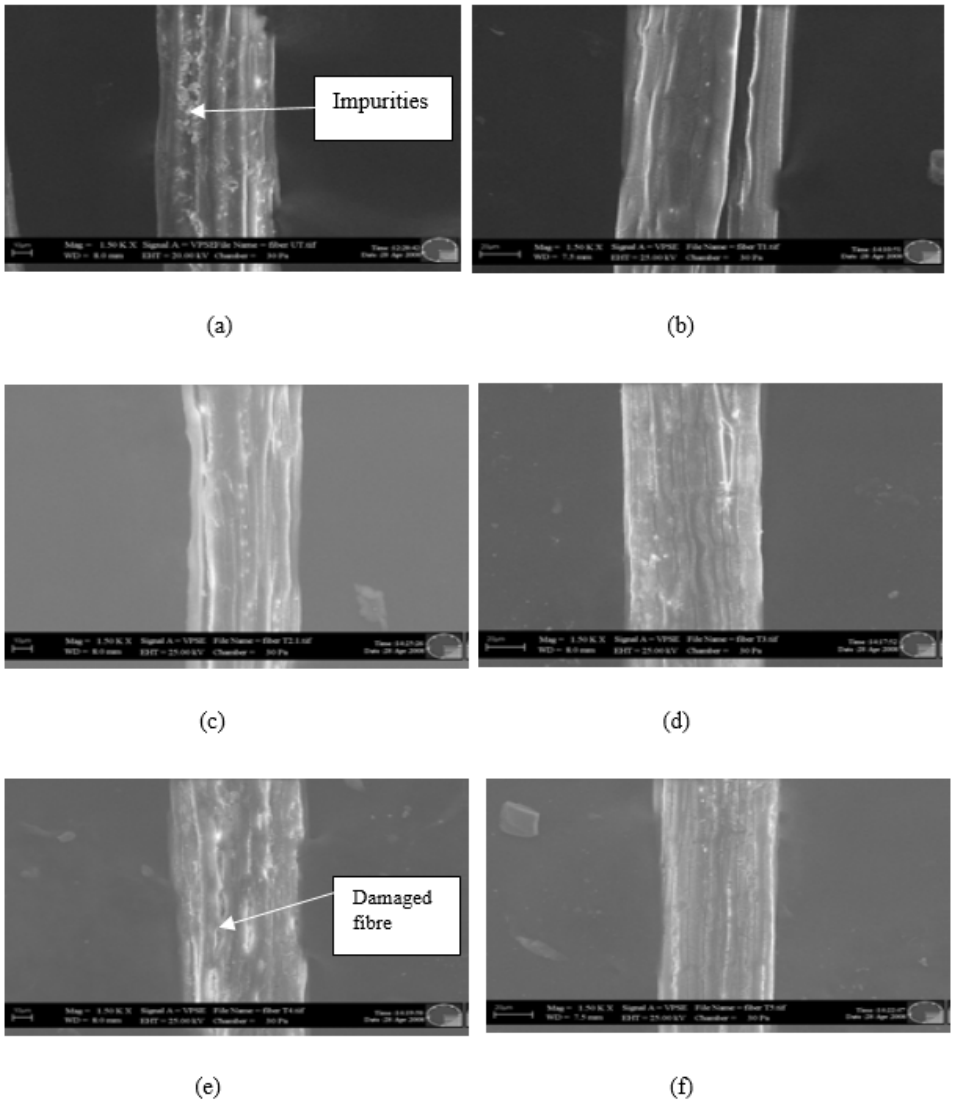

Figure 5. SEM images of untreated and treated kenaf fibre (Mohd Yuhazri et al., 2012) (a) Untreated kenaf fibre (b) 12hours immersion in 3% alkaline solution (c) 24hours immersion in 3% alkaline solution (d) 12hours immersion in 6% alkaline solution (e) 24hours immersion in 6% alkaline solution (f) 12hours immersion in 9% alkaline solution

this treatment is the organosilanes which developed to bond mineral fibres to polymer. The organo-functional group in the coupling agent trigger the reaction with the polymer, either by copolymerization and/or creation of an interpenetrating network (IPN) (Plueddemann, 1991). Weyenberg et al. (2003) investigated the effect of chemical treatment on flax fibres composites and stated the the curing reaction of silane treated natural fibre enhances the wetting of the resin. Lee et al. (2009a) used 3-Glycidoxypropyl trimethoxy silane (GPS) as coupling agent and hot pressing in PLA/Kenaf fibre composites to improve the interfacial adhesion in the carding process and reported that the effects of silane coupling agent on composite properties was highly beneficial leading to increase moduli and heat deflection temperature as well as reduced water swelling. In a similar vein, Huda et al. (2008) had attempted to use 3-aminopropyltriethoxysilane (ASP) coupling agent in kenaf fibre treatment and reported improved compatibility between the kenaf fibre and PLA resin. The surface treated kenaf-PLA composites possessed superior mechanical properties when compared to the composites made from the untreated fibres (Huda et al., 2008). Xu et al. (2009) carried out a research on the thermomechanical properties of the silanized-kenaf/polystyrene composites. The authors used synthesized polymeric coupling agent to modify the kenaf fibre. It was reported that polymeric coupling agent treatment of kenaf fibre has increased the fibre-matrix interaction through condensation reaction between alkoxy silane and hydroxyl groups of kenaf cellulose. Dynamic Mechanical Analysis (DMA) results revealed that treated kenaf fibre composites had higher E^1 and lower tan δ signifying a greater interfacial bond strength and adhesion between the fibre and the matrix resin. The SEM images of the untreated kenaf fibre and treated kenaf fibre with tetrahydrofuran-polymeric coupling agent are shown in (Figures 6a and 6b). Figure 6 (a) shows the presence of wax, oil and surface impurities. The existence of these materials will affect the mechanical behaviour of the fibre composites. Also shown in Figure 6(b) is the surface of the treated kenaf fibres. It was observed by the researchers that the impurities had been cleaned without roughing the fibre surface.

Graft copolymerization of kenaf fibre. Graft copolymerization of natural fibres is an effective technique of surface treatment of natural fibres. This method involves initiation by free radicals on the vinylic monomers onto the cellulose. These free radicals are formed as an outcome of a reaction of the cellulosic chain in a redox system. The oxidation of the anhydroglucose units in the reaction occurs along the cellulosic chain and macro cellulosic radicals are created on the fibre surface (Misra et al., 2002; Valadez et al., 1999). Mohamed et al. (2013a) investigated the effect of partial delignification of kenaf bast fibre for radiation graft copolymerization. It was found that delignification condition at 80^0C for 6 hours with 0.5% $NaCl_2$ gave 91% of lignin removal from the kenaf bast fibres. In a similar manner, Mohamed et al. (2013b) carried out a research on graft polymerization of micelle size 3% 4-chloromethyl styrene (CMS) emulsion on kenaf fibre. The influence of micelle size over

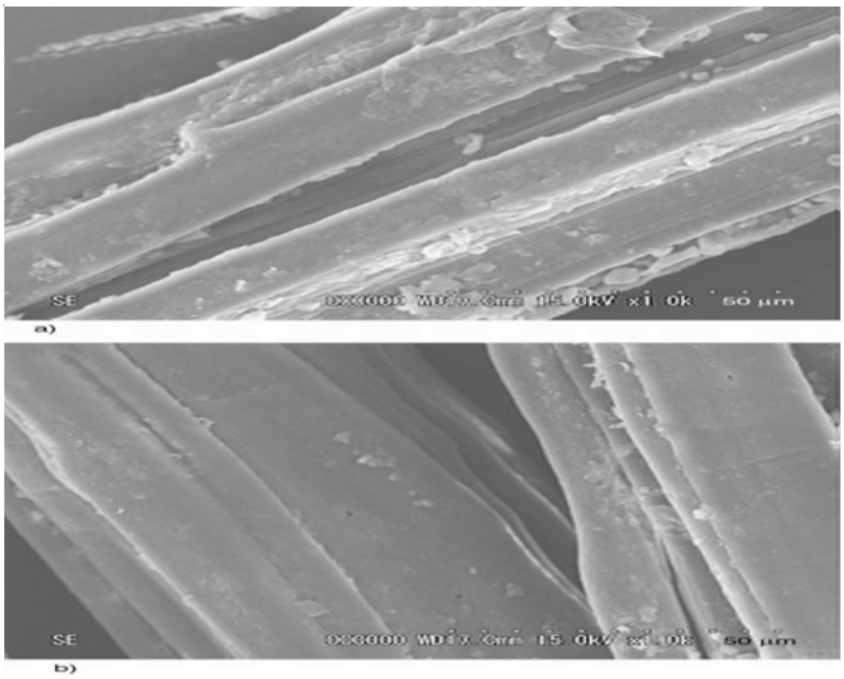

Figure 6. SEM images of longitudinal views of (a) untreated kenaf fibre and (b) treated kenaf fibre with tetrahydrofuran-polymeric coupling agent (Xu et al., 2009)

time was explored by adjusting the ratio of CMS to Tween 20 (10:1,10:2,10:4) at CMS concentration 0.2-5% in emulsion with 350 micelles at various CMS concentrations at a dose of 150KGy. It was found by the authors that the degree of grafting (Dg) was strongly dependent on the monomer concentration and time. However, the increase in micelles diameter from 250nm to 500nm results in the increased in Dg from 3% to 153%. It was concluded that the enhancement of grafting yield is governed by emulsion break-down mechanisms through radical effect during radiation which induced graft polymerization. Graft copolymerization of glycidyl methacrylate onto delignified kenaf fibres have been investigated by Sharif et al. (2013). The kenaf fibres was prepared via pre-irradiation grafting method. Fibres were first treated with sodium chlorite solution before been used as trunk polymer. Treated kenaf fibres were irradiated by electron beam followed by grafting reaction in glycidyl methacrylate/water emulsion system. The degree of grafting was determined as a function of absorbed dose, reaction time, reaction temperature and concentration of monomer. The research results showed that the lignin content of kenaf fibre was decreased from 14.3% to as low as 3.3% with the increased sodium chlorite concentration. This was evident according to the authors by SEM images presented in Figure 7 which shows treated kenaf fibre surface cleaner and smoother when compared with the untreated kenaf fibre surface.

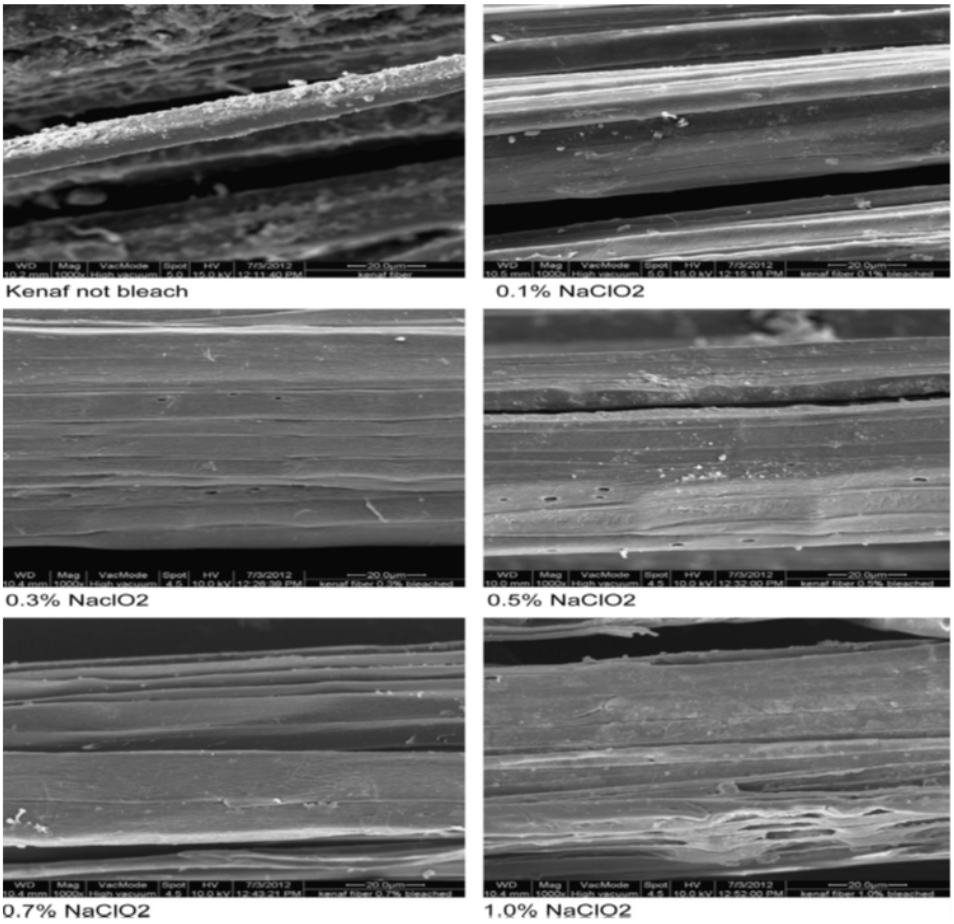

Figure 7. SEM images of kenaf fibre before and after treated with sodium chlorite (Sharif et al. 2013)

Properties of Kenaf Fibre

Researchers in the past have carried out numerous studies to determine kenaf fibre properties and the processing methods associated with the optimal properties. It was noticed from the results presented by researchers, not identical, this may be as a result of variation in categories of kenaf fibres been utilised such as the source of kenaf fibre, retting process, age, body of the plant from which the fibre is extracted, environmental conditions of the site etc. It is additionally fascinating to note that natural fibre for instance, kenaf fibre have unpredictable cross-sectional region that changes along the length of the fibre which influence the mechanical properties of the fibre. Ochi (2008) investigated the effect of environmental temperature on the growth of the kenaf plant and on the tensile and elastic

properties of the kenaf fibres and kenaf/PLA resin composites. The study showed the temperatures and heights of grown kenaf plant under two different conditions. It was established that the kenaf plant which matured at a mean temperature of 22°C had a height of 2000 mm from the ground while the one that matured at a mean temperature of 30°C had a height of 3650 mm from the ground after 168 days. The researcher stated that the production of good strength kenaf fibre reinforced plastic essentially need fibres that were gotten from the area of the plants nearest to the ground. The tensile strength and elastic modulus of kenaf fibres grown in different temperatures are shown in Figure 8. The study concluded that the tensile strength and elastic modulus of kenaf grown under an average temperature of 30°C were greater than those grown under average temperature of 22°C.

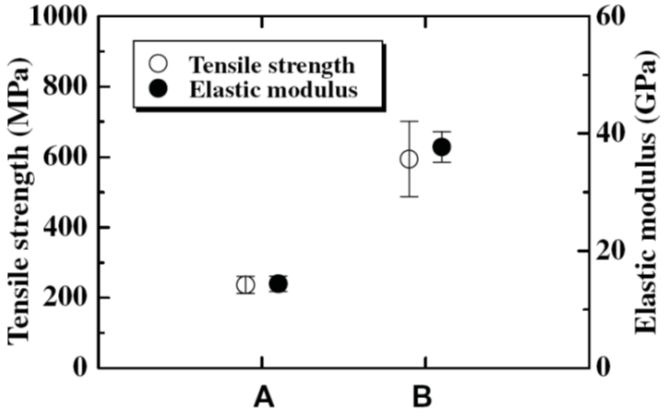

Figure 8. Tensile strength and elastic modulus of kenaf fibre, (A=22°C, B=30°C) (Ochi, 2008)

Kenaf fibres properties presented by several authors are shown in Table 2. A comparison of literature data concerning mechanical properties of kenaf fibres versus E-glass presented by several authors (Mohanty et al., 2000; Mohanty et al., 2005; Parikh et al., 2002) in Table 3, indicates that kenaf fibre could be a decent contender for reinforcement of great performance bio-based polymeric composites.

PROPERTIES OF KENAF REINFORCED COMPOSITES

Jush et al. (2016) illustrated that kenaf was found to be comparatively much available and relatively inexpensive in required form when compared with other kinds of natural fibre reinforced materials. The authors stated that kenaf was tagged as commercial kenaf owing to its potentials as raw materials for variety of products in the industrial and manufacturing sectors. Furthermore, kenaf like most other natural vegetable fibres exhibit high specific mechanical properties, easily recyclable, low density and maintain a competitive price (Mitchell, 1986; Nashino et al., 2003).

Table 2

Properties of kenaf fibres reported by different researchers

Diameter (μm)	Density (g/cm^3)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at break (%)	Reference(s)
55-60	1.2	350-600	40	2.5-3.5	Fiore et al. (2015)
-	1.45	930	53	1.6	(Akil et al., 2011; Mohanty et al., 2000; Reza et al., 2014a)
-	1.5	350-600	40	2.5-3.5	(KENAF ECO-fibres, 2005; Rassmann et al., 2011)
-	1.4	284-800	21-60	1.6	(Holbery & Houston, 2006; Sivakumari et al., 2017)
140	-	223	14	-	Shinchi et al. (2005)
81	-	250	50	-	Lee et al. (2009b)
-	-	295-1191	2.86	3.5	(Cheung, Ho, Lau, Cardona, & Hui, 2009)
-	0.749	223-624	11-14.5	2.7-5.7	(Graupner et al., 2009; Malkapuram et al., 2008)
-	1.2	295	-	3-10	Jawaid and Khalil (2011)
-	1.26	393-773	26.5	1.5-1.8	Zamri et al. (2016)
14	-	223	15	-	Ozturk (2010)
68.5	1.31	476	25.1	-	Munawar et al. (2007)
61	1.386	110-358	17-25	-	Osman et al. (2013)
78	1.04	448	24.6	-	Cao et al. (2007)
24	-	135-232	15-24	-	Harun et al. (2009)

Table 3

Kenaf fibres and E-glass fibres properties

Fibre	Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation break (%)	Reference(s)
Kenaf fibres	1.45	284-800	21-60	1.6	(Mohanty et al., 2000; Parikh et al., 2002)
E-glass fibres	2.55	2000-3000	70	2.5	Mohanty et al. (2005)

Mechanical Properties

The performance and behaviour of any structural constituents according to Akil et al. (2011), is usually attributed to their mechanical qualities, for example, compressive strength, tensile strength, flexural strength, impact resistance properties and wear properties. The authors further stated that these characteristics/qualities are relevant parameters used to fathom the material capacity, particularly under critical and severe loading arrangements which

are directly linked to engineering performance. Several research works have been carried out on kenaf fibre polymer composites to characterize fully its mechanical behaviour and properties (Anur & Zuraida, 2011; Fiore et al., 2015; Reza et al., 2014b; Yousif et al., 2012). Basically, the tensile strength and flexural strength of kenaf fibre reinforced composites differ which is dependent on the categories of fibre, fibre orientation (unidirectional or random), form and content (fabric or fibre), and the type of matrix used. Table 4 shows the mechanical properties of kenaf fibre reinforced composites presented by different researchers.

Thermal Properties

Thermal properties are vital characteristic of kenaf fibre reinforced composites which requires evaluation to understand fully the thermal behaviour of kenaf composites. The thermal decomposition of natural vegetable fibres including kenaf fibre is usually initiated with low temperature of hemicelluloses deterioration and subsequently with sharp drop of weight associated with cellulosic pyrolysis. Several methods are currently being employed to determine the thermal property of composites: Dynamic Mechanical Analysis (DMA), Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). TGA allows the determination of the mass of composites sample lost due to temperature, while the DSC scan could estimate the various vital parameters for example, the melting temperature (Tm), glass transition temperature (Tg), level of crystalline and oxidation (Hassan et al., 2011; Julkapli & Akil, 2010). Hassan et al. (2011) investigated the thermal characteristic on kenaf fibre filled by chitosan bio-based composites. The two methods considered were the DSC and TGA. At the course of DSC testing, heating scan analysis was carried out twice and it was discovered that most specimens showed a wide endothermic peak throughout the scan that is related to the hydration process. For the subsequent heating scan, it was noticed by the authors that the inclusion of kenaf particles to the chitosan led to decrease of the endothermic temperature. Nevertheless, no significant differences in enthalpy data was noticed with the different fibre volume fraction used. The TGA results from the same research indicated that the incorporation of kenaf particles to the chitosan have not no significant effect on the thermal performance of the chitosan film. DMA on the other hand is an essential tool used to determine the visco-elastic behaviour of polymer plastic and composite materials. The measurement involves the monitoring of the time condition of the alteration performance of a specimen under periodic, extremely sinusoidal deformation energy with small amplitudes. El-shekeil et al. (2012) investigated the influence of volume fraction of fibre on the thermal (i e.TGA) properties of kenaf fibre/ thermos-plastic polyurethane polymeric composites. Different fibre loading of 20%, 30%, 40% and 50% by weight was used and it was observed that fibre loading decreased the

Table 4

Mechanical properties of kenaf fibre reinforced composites from previous researchers

Matrix	Fibre content (M%)	Tensile strength (MPa)	Young modulus (GPa)	Flexural Strength (MPa)	Flexural modulus (GPa)	Impact strength (Kj/m^2)	Processing	Treatment	Reference (s)
PLA	40	82(52)	8(3.4)	126(96)	7(3.2)	14(17)	CSM	-	Graupner and Mussii (2011)
PHB	40	70(22)	6.1(22)	126(43)	7(1.6)	10(5)	CSM	-	Graupner and Mussii, (2011)
Epoxy	30	124	14.4	-	-	-	UD	NaOH (5%)	Reza et al. (2014b)
Epoxy	40	164	18.15	-	-	-	UD	NaOH (5%)	Reza et al. (2014b)
PP	40	-	-	27	2	-	Random mat.	-	Wambua et al. (2003)
Polyester	64	-	-	123	13	-	UD	NaOH (6%)	Aziz and Ansell (2004)

Table 4 *(Continue)*

Matrix	Fibre content (M%)	Tensile strength (MPa)	Young modulus (GPa)	Flexural Strength (MPa)	Flexural modulus (GPa)	Impact strength (Kj/m^2)	Processing	Treatment	Reference (s)
PLA	35	131(33)	15(3.8)	160(72)	11.5(4.9)	-	UD		Ochi (2008)
Epoxy	30	64	4.5	90	4.9	-	CSM	-	Rassmann et al. (2011)
Polyester	30	52	6.7	98	5.2	-	CSM	-	Rassmann et al. (2011)
Vinyl ester	30	57	5.6	84	4.7	-	CSM	-	Rassmann et al. (2011)
PP	30	40	1.7	43	-	-	CSM	NaOH (5%)	Asumani et al. (2012)
PP	30	58	2.8	59	-	-	CSM	NaOH (5%)-Silane (5%)	Asumani et al. (2012)

thermal performance of composites and it was stated that the increase weight loss with fibre loading agrees with the research works conducted by (Bijwe et al., 2002; Harsha & Tewari, 2003). However, the thermal constancy of composites remained superior to the kenaf fibre. Figure 9 shows the effect of fibre loading on the TGA of thermos-plastic polyurethane /kenaf fibre composites.

Water Absorption Properties

The main issue with the utilization of natural fibre composites is connected to the its deterioration at high moist environments and absence of adhesion between the fibre-matrix interface if the fibres are not modified properly. Moisture ingress into composites, reduces fibre-matrix interfacial adhesion, drops the glass transition temperature, hydrolyses and occasionally introduced micro-cracks in the matrix (Grant & Bradley, 1995). Water can be present in polymer in numerous ways: in form of bound water, as characterised by robust interaction with the molecule of matrix and free water, existing in vessels and micro voids

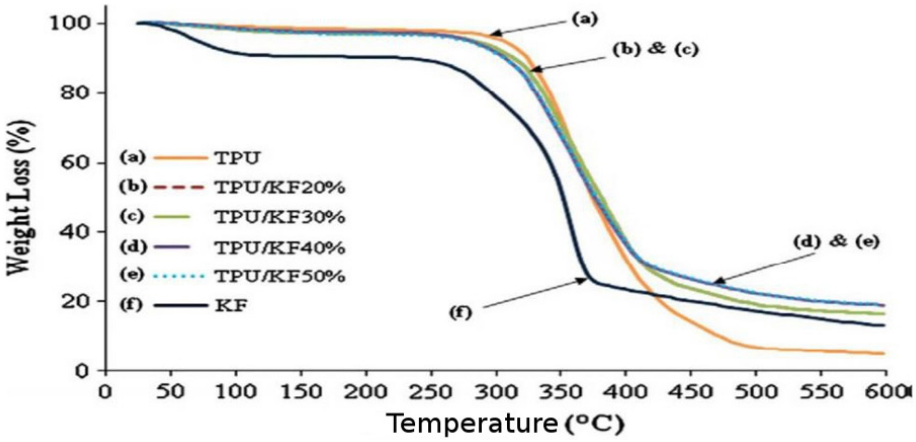

Figure 9. Effect of fibre weight fraction on the DTA of thermos-plastic polyurethane/kenaf fibre composites (El-shekeil et al., 2012)

in the polymer (Fraga et al., 2007). Several researchers have shown certain responsiveness of the mechanical and the thermal properties to moisture uptake on the utilization of natural vegetable fibre polymer composites and recommended that it could be lowered through fibre surface modification and as well as the use of coupling agents (Rashdi et al., 2009; Wambua et al., 2003). Generally, moisture ingress into composite relies upon variables, for example, weight portion of fibre, void volume, thickness of framework, fibre treatment, dampness and temperature (Najafi et al., 2008). Similarly, Nosbi et al. (2010) stated that water uptake behaviour of polymer composite was of great worries in fibre composites structure,

particularly for lignocellulosic fibre polymer composites. The researchers opined that for any composite system, the water uptake characteristics was determined by the quality of fibre, orientation of fibre, porosity of the fibres, area of unprotected surface, temperature, void content and sorption behaviour of the individual component. The percentage of weight gain is usually determined by the weight difference between specimens immersed in water and dry specimens using equation 3 (Akil et al., 2010):

$$M\% = \frac{M_1 - M_0}{M_0} \times 100 \quad [3]$$

Where M (%) is the moisture content in percentage, M_1 (g) is the weight of the wet sample at a given time and M_0 (g) is the initial weight of the sample. Rassmann et al. (2010) carried out a research on the effect of fabrication methods on the properties of kenaf fibre composite laminates and reported that water absorption was not appreciably changed by any preparing condition aside from by pressurization at low fibre weight division, water assimilation increments with fibre weight portion, and last however not the slightest, water retention makes all dimensions of composite to expand. However, the expansion of the length and of the width is very minimal when compared to the expansion in thickness. Mazuki et al. (2011) reported water absorption effect on the dynamic mechanical analysis of pultruded kenaf fibre reinforced polymer composites. The period of immersion of samples was for 24 weeks and it was reported that the thermal properties was extremely affected by the presence of absorbed water in the specimen. It also reviewed that the fibre is highly exposed to solution after 24 weeks of immersion from the morphological study. The effect of different conditions such as sea water, rain water and tap water on the mechanical properties of kenaf composites and kenaf hybrid (fibreglass) composite was investigated by Salleh et al. (2014). Specimens were immersed up to 60 days and the authors reported that both kenaf polyester and kenaf hybrid polyester composites show reduction on mechanical properties after immersion in the solutions. It was concluded that kenaf polyester and kenaf hybrid polyester followed the fickian behaviour after 40 days of immersion, where it reached equilibrium at a certain specific immersion time. Figure 10 shows the behaviour of water absorption of both kenaf polyester and kenaf hybrid polyester composites.

KENAF FIBRE IN HYBRID COMPOSITES

The incorporation of different types of fibres into a single matrix has led to the development of hybrid bio composites. A current study had shown that the hybridisation of vegetable fibre with limited quantity of synthetic fibre makes the composite less susceptible to moisture uptake as well as enhances its tensile properties. When diverse types of fibres are introduced in a composite, the benefit of one kind of fibre could make up for the shortcoming of the

other fibre. Along these lines, an adjust in cost and execution qualities, for example, light weight, high strength and stiffness can be accomplished (Karahan & Karahan, 2015). Sharba et al. (2016) did an investigation on the impact of kenaf fibre orientation on mechanical properties and exhaustion life of a polyester based glass/kenaf hybrid composite They found that the monotonic and weariness properties of the hybrid composite relied upon fibre orientation, which fundamentally influenced the mechanical strength, and the hybridisation

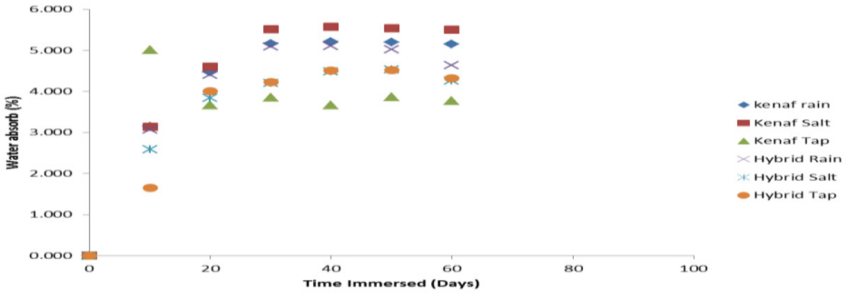

Figure 10. Water absorption of kenaf polyester and kenaf hybrid (fibreglass) polyester composites (Salleh et al., 2014)

of kenaf and glass enhanced the exhaustion debasement coefficient of the composite. Yahaya et al. (2016) demonstrated the effect of fibre orientations on the mechanical properties of kenaf-aramid hybrid composites and reported the tensile strength of kenaf woven hybrid composite was 20.78% and 43.55% more than the unidirectional samples and the mat samples. The Charpy impact test was also compared and the same trend was observed. The authors concluded that woven kenaf fibre could be a good candidate material for the production of hybrid composite with good tensile properties and impact resistance. Alavudeen et al. (2015) investigated the mechanical properties of woven banana fibre, kenaf fibre and banana/kenaf hybrid fibres composites. It was reported that the mechanical strength of woven banana/kenaf fibre hybrid composites increased due to the hybridization of kenaf with banana fibres. The tensile strength, flexural strength and impact strength of woven hybrid composites of banana/kenaf fibres are superior to those of the individual fibre composites. Hybrid bio-composites in unidirectional arrangement using kenaf fibre, bamboo fibre and coir fibre to reinforced polylactic acid resin (PLA) was studied by Yusoff et al. (2016). Three types of composites made up of kenaf fibre-coir/polylactic acid, bamboo-coir/polylactic acid and kenaf-bamboo-coir/polylactic acid composites were tested to failure in tension and flexure. It was recorded that the tensile strength of kenaf-bamboo-coir/polylactic acid composites have a value of 187MPa, roughly 20% and 78% more than bamboo-coir/polylactic acid composites and kenaf-coir/polylactic acid. Young moduli

value ranges from 6.0GPa to 7.5GPa for the three composites. The kenaf-bamboo-coir/polylactic composites have flexural strength values 199MPa and bamboo-coir/polylactic acid composites have 206MPa, which is roughly 16% and 20% more than kenaf-coir/polylactic acid composites. The authors went further to state that the kenaf-coir/polylactic acid composites gave the highest flexural modulus and it was put at approximately 70% more than the two other combinations. The entire research was concluded by saying that the hybridization of high stiffness and strong kenaf fibre and bamboo, and good ductility of the coir fibre improved tensile strength and flexural strength of composites as compared to the single fibre composites.

KENAF FIBRE-REINFORCED COMPOSITES APPLICATIONS

Natural fibre-based composite materials including kenaf fibre reinforced composite have recently been seen as a competitor for metallic fibres and synthetic fibres. Many scientists and researchers are now trying to produce structural elements, electrical components, automotive components, aircraft parts and other products by using natural vegetable fibre as reinforcements. Hafizah et al. (2014) had successfully used kenaf fibre reinforced polymer laminates to strengthen reinforced concrete beams. The researchers reported increased in the mechanical performance for all the strengthened beams and that the maximum flexural strength was increased by 40% fibre weight. Interior headliner model for an automotive have be produced using PLA/kenaf fibre content at 50% fibre weight and it was confirmed that the mechanical properties are satisfactory. Also, Davoodi et al. (2010) had used kenaf/glass hybrid epoxy composite for bumper beam of passenger car. Some conceivable utilizations of kenaf fibres and its bio-based composites are itemized below:

- Kenaf fibres is currently been viewed as a standard and commonplace raw material in the creation of particleboards, feeds for animal, paper, textiles materials and fuel (Alexopoulou, 2013; Juliana et al., 2012; Loynd, 2010).
- Kenaf fibres are been utilized as a part of assortment of utilizations, for example, burlap packs, twine, sacks, ropes, canvas, cordage, floor coverings, mechanical and business textures and bio-plastic composites (Cheng et al., 2004).
- Kenaf's internal woody main elements had high sponginess and numerous scientists have explored its uses in various field, for example, seats for car industry, sewage slop, treating the soil as a building operator, particleboard in dashboards (Webber, 1994).
- Kenaf has been utilized as dynamic retentive, creature bedding and poultry litter, gardening soil revision, adequately utilized for dangerous disposed of waste water expulsion as oil slicks on water, squander tidy up and evacuation of synthetically debased soil's organization (Tilmo et al., 1988; Webber et al., 1999; Webber et al., 2002b).

- Automotive inside coating, outside car parts, for example, front and back guards, wallboards, roof and furniture (Khan, 2011; Pang et at., 2015).
- Genetic engineering practices towards resolving problems associated with the repair and rebuilding of harmed or non-utilitarian tissues (Cheung et al., 2009).
- Bio-medical practices for example gene/drug delivery, orthopaedic and cosmetic dentistry, implantable prosthesis, soft and hard tissues application including external fixation, hip arthroplasty, and deck screw and pins (Namvar et al., 2014).

CONCLUSION

This study reviews that kenaf fibre shows a bright future when compared with other fibres. Kenaf fibre polymeric composite has good potential to substitute glass fibre reinforced composite and other petroleum based composites because it has commensurable physical and mechanical properties to the latter. Most importantly, kenaf fibre reinforced polymer composite has lower density, eco-efficient and cost effective when compared to petroleum-based composite. Interestingly, kenaf fibre reinforced polymer composite utilises various manufacturing processes such as pultrusion and filament winding that have never been used with other lignocellulosic fibres before. Interfacial bonding between kenaf fibres and matrix is still the key issue in terms of the overall performance, since it dictates the final properties of the composite, but many studies have proved that proper surface treatment or surface modification can overcome this deficiency since kenaf fibre is hydrophilic in nature. The future of kenaf fibre as stated earlier seems to be bright but there is need for relentless research and development as well as organized and commercialized policy. It is also important for kenaf fibre to be delivered in direct roving arrangements, which make it easier for the fibre to be utilized as material in reinforced composite manufacturing because, it will produce fibre-reinforced polymer composite with fibre in constant and continuous cross-section.

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