

KENAF FIBRES AS REINFORCEMENT FOR POLYMERIC COMPOSITES: A REVIEW

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ABSTRACT

In a view to reduce the cost of production and the harmful destruction of our environment, so many research work has been conducted and still ongoing as to the possibility of using natural fibres that are wholly degradable in combination with biodegradable thermoplastic materials. This has shown significant result so far and this effort needs to be further consolidated so that our environment can be safe and saved from destruction. It is for this reason that this paper is geared through reviewing studied and published results and brings out converging problems associated with biodegradable composite and partially degradable ones so that these associated problems can be tackled in further research. This review however will focus on Kenaf; a very important natural fibre with robust mechanical properties. Good number of journal papers have been reviewed here that touch on cultivation of kenaf and its consequent effect, chemical treatment of natural fibres, matrix combinations, processing techniques, environmental effects on composite, critical fibre length, some works done on Malaysian cultivated kenaf and use of coupling agents to improve linkages between fibre and polymeric matrixes. Most of the studies so far discussed tend to arrive at the problem of wettability of the composites which inhibits further increase in fibre loading and consequent fibre pull-out. Various areas of further study have been highlighted to tackle the aforementioned problems in composite production.

Keywords: Fibre, Kenaf, Polyethylene, Processing, Wettability

1.0 INTRODUCTION

The need for the world to fully become environmentally friendly and to fight the sometimes painful instability and non availability of petroleum based thermoplastics couple with the need to make manufactured products more accessible and affordable to consumers have necessitated the application of more effort into processing and production of natural fiber composites which can result in reduction of production cost to companies and impart greater mechanical properties to polymeric materials. As the world push towards making the world 'green', the need for global participation in saving our environment and making the world more

affordable to live in cannot be overemphasized. The need for biocomposite have become imminent because of increase in price of wood resources, availability of new sources of fibres, concern for the environment, technological advancement, competitiveness, research and development in developed countries couple with the driving forces for this commodity such as market readiness and acceptance, market outlook and trends, product substitution and concern for the environment (Harun et al. 2009). It is important to note the variety of processing parameters like fibre area fraction, molding temperature and forming pressure as this has great influence on the mechanical properties of composites. This overview tends to focus on kenaf in combination with other polymeric materials with a view to expose other areas of further studies. It is well known that the performance of composite depends on the properties of the individual components and their interfacial compatibility. For numerous applications, plant fibres have to be prepared or modified (Cheremisinoff 1997; Van Sumere 1992). In real perspective, properties like Homogenization of the properties of the fibres, degree of elementarization and degumming, degree of polymerization and crystallization, good adhesion between fibre and matrix, moisture repellence and flame-retardation, which are factors considered in using natural fibre, can be partly influenced by different fibre separation process, but subsequent fibre treatment process are more influential (Bismarck et al 2005). (Satyanarayana et al. 1986) established a semi-empirical relationship to correlate the fibre elongation ϵ and the microfibrillar angle θ . This equation can be represented as:

$\epsilon = 2.78 + 7.28 \times 10^{-2} \theta + 7.7 \times 10^{-2} \theta^2$ and that of the tensile strength σ and microfibrillar angle θ with the cellulose content W as $\sigma = 334.005 - 2.830 \theta + 12.22W$.

Depending on their origin, natural fibers can be generally grouped into bast (jute, flax, hemp, kenaf, mesta), leaf (pineapple, sisal, henequen, screw pine), and seed or fruit fibers (coir, cotton, oil palm)(Young 1997). (Habibi et al. 2008) explained that cellulose is the main component of natural fibers, and the elementary unit of a cellulose macromolecule is anhydro-d-glucose, which contains three hydroxyl (OH) groups. These hydroxyl groups have been reported to form hydrogen bonds inside the macromolecule itself (intramolecular) and between other cellulose macromolecule (intermolecular) which is why all natural fibers are hydrophilic in nature.

When natural fibres are closely compared to inorganic fibers, it presents some well-known advantages such as lower density and cost; are less abrasive to the processing equipment, harmless, biodegradable, renewable, and their mechanical properties can be comparable to those of inorganic fibers, furthermore, they are recyclable, easily available in most countries, easy fiber surface modification, and its relative nonabrasiveness.etc (Li et al. 2008; George et al. 2001). Much work has been done on virgin thermoplastic and natural fiber composites, with successful prove of their application to various fields of technical applicability, especially for load-bearing application (Lei et al. 2007). Thermoplastics such as polyethylene (PE)(Lundin et al. 2004; Foulk et al. 2004), have been compounded with natural fibers (such as wood, kenaf, flax, hemp, cotton, Kraft pulp, coconut husk, areca fruit, pineapple leaf, oil palm, sisal, jute, henequen leaf, ovine leather, banana, abaca, and straw) to prepare composites(Lei et al. 2007). Furthermore, (Lei et al. 2007) investigated the use of recycled high density polyethylene (HDPE) and showed that the mechanical properties of the fiber reinforced recycled HDPE compared well with those of virgin HDPE/fiber composites. This has open up opportunities not only for the use of virgin thermoplastics in composite formation, but also the use of recycled plastics in natural fibre composite production.

Kenaf (*Hibiscus cannabinus*, L. family *Malvaceae*) is seen as an herbaceous annual plant that can be grown under a wide range of weather condition; for example, it grows to more than 3m within 3 months even in moderate ambient conditions with stem diameter of 25-51mm. It is also a dicotyledonous plant meaning that the stalk has three layers; an outer cortical also referred to as ('bast') tissue layer called phloem, an inner woody ('core') tissue layer xylem, and a thin central pith layer which consist of sponge-like tissue with mostly non-ferrous cells (Sellers Jr et al. 1999; Ashori et al. 2006). The history of Man can be as well linked to the use of fibres; traditionally as a rope, canvas, and sacking. Very high interests in Kenaf cultivation in recent years have been achieved for two main reasons; one is kenaf's ability to absorb nitrogen and phosphorus included in the soil (Abe & Ozaki 1998). The other is that kenaf's ability to accumulate carbon dioxide at a clearly high rate (S. Amaducci et al. 2000). The merits of using natural lignocellulosic fibres as reinforcements of the matrix can't be overemphasized. Kenaf is clearly known as a cellulosic source with economical and ecological advantages. (Nishino et al. 2003) reported that "Kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability". Recently, kenaf is used as a raw material to be alternative to wood in pulp and paper industries for avoiding destruction of forests(Pande & Roy 1998), and also used as non-woven mats in the automotive industries(Magurno 1999), textiles (Ramaswamy et al. 1995), fibreboard (Kawai et al. 2000). Kenaf bast fiber has been reported to have superior flexural strength combined with its excellent tensile strength that makes it the material of choice for a

wide range of extruded, molded and non-woven products as widely discussed by other authors. Natural and wood fibre plastic composites have gained significant interest in the last decade. The retail value of this industry has been growing nearly 16% annually since 1998, and valued at over \$750 millions (Wolcott & Smith 2004).

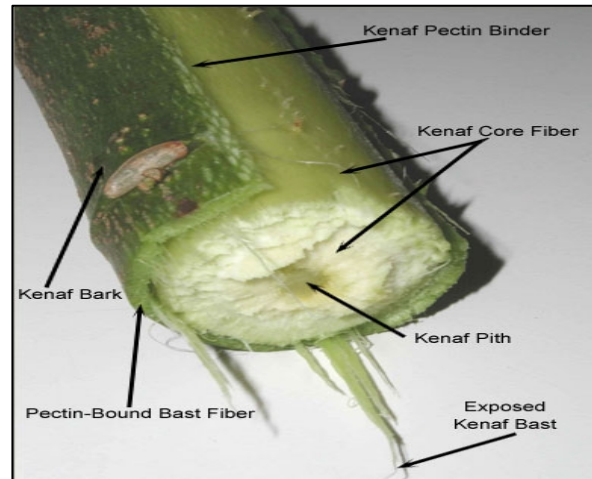


Fig1. Exposed physical appearance of kenaf (Khalina et al. n.d)

1.1 Objective of the review

This review is geared towards highlighting the ground breaking achievement of scholars on the reinforcement of Kenaf with some Polymeric materials with a view to open further areas of study on this type of composite for academic and industrial use.

2.0 FIBRE SURFACE MODIFICATION/ ADHESSION PROPERTIES

Enhancing the effectiveness of interface adhesion between cellulose-based fillers and thermoplastics has attracted the attention of scholars in the last twenty years. Most of these studies have been carried out on wood fibres. Several techniques ranging from grafting of short-chain molecules and polymers onto the fibre surface to using coupling agents and radical induced adhesion promoters have been reported for improving interfacial bonding(Van de Weyenberg et al. 2003; Nishino et al. 2003; Ochi 2007; Chin & Yousif 2009). As reported, Grafting improves wetting of the fibre with matrix by hydrophobizing the fibre surface and promotes interfacial bonding by diffusion of the chain segments of the grafted molecules into the matrix. Coupling agents and radical induced adhesion enhance interfacial bonding through producing covalent bonds between the fibre and the matrix (Brahmakumar et al. 2005; Abdelmouleh et al. 2007).

Similarly, several strategies of surface modifications aiming at improving the compatibility between cellulose fibres and polymer matrices were recently reviewed (Herrera-Franco & Valadez-Gonzalez 2005; Van de Weyenberg et al. 2003). Coupling agents bearing two reactive groups can be used to chemically modify the interaction surface of fibres and that of polymeric

materials with a view to allowing the establishment of covalent bond between them which can most likely result in getting materials with very good mechanical properties. i.e. interaction between the OH functional group at the fibre surface and the copolymerization of the other reactive group with that of the matrix material. A lot of coupling agents have been investigated, some of these anhydrides included, maleated polymer, (Panthapulakkal et al. 2005; Keener et al. 2004), isocyanates, (George et al. 2001; Qiu et al. 2005), and alkoxysilanes (Ramaswamy et al. 1995; Colom et al. 2003), as recently reviewed (Belgacem & Gandini 2005). Within these different reagents, maleated polypropylene (MaPP) or polyethylene (MaPE) have reportedly shown significant enhancement in tensile and flexural strength, ranging from 40% up to 80%, as pointed out when they are blended with cellulose fibres before mixing with matrix (Keener et al. 2004). Similarly, Silane as coupling chemical has some major advantages; economically it is commercially available; secondly, they bear an alkoxysilane group that is capable of reacting with the OH-rich surface of natural fibres at one end while at the other end, they have a large number of functional groups which can be tailored as a function of the matrix to be used. The last feature clearly ensures, at least, a good compatibility between the reinforcing element and the polymer matrix or even covalent bonds between them (Abdelmouleh et al. 2007). (Edeerozey et al. 2007), investigated the chemical modification of kenaf fiber using NaOH at different concentrations and discovered that the alkalization treatment of kenaf can improve its mechanical properties significantly as compared to untreated kenaf fiber through its morphological and structural changes. They noted that Chemical treatment of the fiber can clean the fiber surface, chemically modify the surface, stop the moisture absorption process and increase the surface roughness if 6% optimum concentration of the alkaline is used. Similarly, (Hazira et al. 2005), further corroborated that fibre treatment enhance greater tensile strength, tensile modulus and elongation at break to certain fibre loading and “Silane which contains two types of reactive groups provides chemical bonding between the hydrophobic LDPE and hydrophilic kenaf fibres”. (Torres & Cubillas 2005), reported previous work on fibre treatment where fibres were pre-washed in a solution consisting of water and 3% non-ionic detergent for 1 h at 70 °C followed by washing with distilled water and air drying in an oven for 24 h at 65 °C. The fibres were then treated with 3% of stearic acid as adequate concentration to achieve a considerable reduction in the size, number of fibre clumps and agglomerates during standard processing operations. In addition, silane-coupling treatment to kenaf fiber has been shown to effectively improve its interfacial adhesion (Nishino et al. 2006).

3.0 MECHANICAL & TRIBOLOGICAL PROPERTIES

So many researchers had tried to look at most of the different fibres available, some in intricate details while

others at the periphery and most of them tracking towards some few key issues; recyclability, affordability, process-ability, loadability through effective wettability of the various natural fibers. Some of these results are herewith reviewed with a view to arrive at a productive and result oriented conclusion that can help in achieving a more robust result in the area of composite technology. Experimental data of natural fibre's mechanical properties, particularly when tested under different processing conditions, have shown inconsistent values in many cases (Torres & Diaz 2004; Torres & Aguirre 2003). The irregular characteristics of these fibres is one of the main reason for this (Torres & Cubillas 2005), which may also be as a result of cultivation, age and specific point on the plants where the fibres are removed as expressed by some scholars. Many scholars have also tried to look at various manufacturing processes in automobile parts production; for example, Hambali et al recently considered and experimented with five different types of manufacturing processes i.e injection molding, resin transfer molding, structural reaction injection molding, reaction injection molding and compression molding for the production of composite automobile bumper using analytical hierarchy process (AHP) concept and discovered that injection molding was the most appropriate out of the five.

In their quest to answer questions on this burning issue of natural fibre composites, (Wambua et al. 2003) evaluated several different natural fiber–polypropylene composites to determine if they had the ability to replace glass fiber–reinforced materials. Polypropylene with a very high melt flow index was used to aid in fiber matrix adhesion and to ensure proper wetting of the fibers. Samples were made with 40% fiber content of kenaf, coir, sisal, hemp, and jute. After the samples were fabricated, tensile and impact tests were run to compare the properties of these composites to those made with glass fiber. The tensile strengths all compared well with glass, except for the coir, but the only sample with the same flexural strength was hemp. It was shown with kenaf fibers that increasing fiber weight fraction increased ultimate strength, tensile modulus, and impact strength. However, the composites tested showed low impact strengths compared to glass material composites. This can be connected with the fact that short fibres tend to display low impact property in most cases when compared to the use of long fibres. This explains the loading of up to 40% and use of high flow melt index of PP to be able to achieve the result recorded in the study. Secondly, fibre glass surface has been reported by many scholars to be more roughened than natural fibre surface and so promote more adhesion than natural fibre composites. This study demonstrated that natural fiber composites have the potential to replace glass in many applications especially if the fibre surface is well treated to enhance adequate bonding with matrix material. In an attempt to fabricate composites with better dispersion and adhesion using Poly L- lactic acid (PLLA), (Nishino et al. 2003) decided to use kenaf fiber sheets. The kenaf fiber bought in sheets, were dried, and then soaked in a dioxane solution under vacuum. Samples from this were easily fabricated and exhibited

good performance with a fiber content of approximately 70% by volume. Fiber orientation played an important role in the final properties of the composite achieved in this study. (Zampaloni et al. 2007), however stressed that one of the main obstacles that needs to be addressed in the fabrication of kenaf fiber-reinforced composites regards uneven fiber distribution. They reported that kenaf fibers are difficult to manually separate and visually disperse evenly during manufacturing, a factor if achieved, can help in getting composite with better properties. Two different composites were manufactured by them; one with long kenaf fibers, approximately 130 mm (5.1 in.) and a second using shorter, chopped kenaf fibers with an approximate length of 20 mm (0.79 in.) in three different processing methods to try and achieve even distribution of fibers. The optimal fabrication method in this work was the compression molding process which proved to sift microfine polypropylene powder and chopped kenaf fibers. A fiber content of both 30% and 40% by weight proved to provide adequate reinforcement to increase the strength of the polypropylene powder, while the use of the coupling agent, Epolene G3015 (3%), enabled successful fiber-matrix adhesion. This work has gone on to show that tensile and flexural strength of composites can be weakened above certain increase in fibre content and therefore the need to note this critical limit during composite production. In fibre composite production, orienting the fibres in parallel direction helped to make distribution of load more effective which was why (Nishino et al, 2003 and Zampolini et al, 2007) reported very high value of young modulus and tensile strength. However, fibre content of composite will depend on the production method to be employed and the end use of the composite because higher fibre loading can reduce the thermal stability of composite. It is therefore critical to consider fibre orientation, loading and even-distribution of fibres with respect to the final use of the composite during production as this will help in achieving adequate load transfer from polymer to the fibre. With unidirectional orientation, a greater even-penetration of polymeric material can be achieved which can ultimately result in higher fibre loading and adequate adhesion with greater load transfer as its consequent effect.

To be able to assess the properties of kenaf from the scratch, (Ochi 2007) described the cultivation of kenaf and application to biodegradable composite materials with an emulsion-type PLA (poly-lactic acid) resin as the matrix. Results showed that the differences in growth conditions can affect the length of the kenaf fibers. Fibers taken from long rod possess greater strength, while those from the bottom section of the plant showed the tendency to have the greatest values of tensile strength. (Ochi 2007) subsequently made a unidirectional biodegradable composite materials from kenaf fibers and an emulsion-type PLA resin and conducted thermal analysis; result revealed that fibers's tensile strength decreased when kept at 180 °C for 60 min while tensile and flexural strength and elastic moduli of the kenaf fiber-reinforced composites increased linearly up to a fiber content of 50%. Its biodegradability was also

examined for four weeks using a garbage-processing machine. Experimental results showed that the weight of composites decreased by 38% after four weeks of composting. The quick biodegradation of the composite has shown that this type of composite can be regarded as "Green Composite" which can serve both as an advantage and a disadvantage depending on its final use. Furthermore, (Ochi 2007) examined the most suitable molding conditions and the resulting mechanical properties of heat-treated kenaf fibers and showed the thermal stability of kenaf fibre can be pegged at 160 °C × 60 min or 180 °C × 30 min during processing or application to avoid thermal degradation. (Liu et al. 2007) described the influence of processing methods and fiber length on physical properties of kenaf fiber reinforced soy based biocomposites by fabricating biocomposites from kenaf fiber and soy based bioplastic by extrusion process, followed by injection or compression molding and discovered that "Compression molded specimens have a similar modulus to injection molded specimens at room temperature, but exhibit a higher heat deflection temperature (HDT) and notched Izod impact strength". It was found that the fractured fiber length on the impact fracture surface increased with increasing fiber length and fiber content. Similarly, they found that modulus increased linearly with fiber volume fraction. Generally with injection molding processing, this does not occur (Liu et al. 2005). At higher fiber volume fraction, the slope decreased due to fiber aggregation and fiber damage during processing. In terms of thermal and mechanical properties, (Liu et al. 2007), showed that compression molding processing has a very high advantage and that Impact strength of compression molded biocomposites was higher than that of the injection molded samples. This difference can be attributed to fiber bridging through fiber pullout (Nielsen & Landel 1994). Because of damage during extrusion and subsequent injection molding, samples may exhibit reduced fibre-bridging effect while compression molded composite should experience higher bridging since damage does not occur in compression molding (Liu et al. 2007). Thus, a greater extent of fiber pullout is expected for compression molded specimens. The extent of fiber pullout was characterized with fiber length on the impact fracture surface. Among the compression molded composites, the impact strength of the composite increased with increases in fiber length and content. This shows that fiber content and fiber length have positive effects on impact strength of biocomposites (Liu et al. 2007) and that the role of fiber bridging effect is dominant in determining the impact strength of fiber reinforced composites. (Shibata et al. 2006), investigated the effects of the number of kenaf layers, heating time and kenaf weight fraction on the flexural modulus of the composite specimen using lightweight laminate composites made from kenaf and polypropylene (PP) fibres by press forming. Result showed that flexural modulus increased with increasing number of kenaf layers and heating time up to certain critical time depending on the number of layers used. Immediately after this critical time, the flexural modulus can begin to

decrease. The increase of the number of kenaf layers contributed to homogeneous PP dispersion in the composite board because more kenaf layers caused better contact between kenaf and PP and prevented PP fibres from easily shrinking by heating. The increase of heating time contributed to better wetting between kenaf and PP as revealed with SEM microphotographs. Similarly, the flexural modulus difference between experiment and calculation, which was predicted by Cox's model, increased with decrease of the bulk density and PP weight fraction in the composite board. This was attributed to the decrease of the contact area between kenaf and PP which decreased stress transfer efficiency by kenaf in the lightweight laminate composites. Thus, the optimized kenaf weight fraction, which showed maximum flexural modulus of the composite specimen, decreased with decrease of the bulk density.

(Nishino et al. 2006), again investigated the mechanical reinforcement of environmentally friendly composite, composed of kenaf fibers as reinforcement and poly-l-lactic acid (PLLA) resin as matrix with a simple wet process. They showed that the stress on the incorporated fibers in the composite under transverse load monitored in situ and non-destructively using X-ray diffraction and the outer applied stress are well transferred to the incorporated kenaf fibers through the PLLA matrix. This suggests a strong interaction between the fiber and the matrix at the surface only. The transverse load applied exposed the miss-alignment of the fibres which prevented the required transfer of load at the critical areas of the composite material. Even though fibre treatment enhanced the composite young modulus, deeper penetration of matrix could not be achieved.

(Mohanty et al. 2005), edited many research work which pointed out that through utilization of an engineered natural fibre concept, superior strength biocomposites can be obtained by surface treatment of bast fibre (e.g kenaf) with leave fibres (e.g. Henequen). Blending them correctly can give optimum balance in mechanical properties because the bast exhibit excellent tensile and flexural properties, while the leave fibre-based composites gives better impact properties to composites. The combination of this two is expected to provide a stiffness-toughness balance in the resulting composites. They further pointed out that the better way by which the maleic anhydride compatibilization chemistry can be implemented during biocomposite fabrication is in a reactive extrusion process where one can add chopped biofibre, polymer matrix and maleated coupling agent in one step, processing them into compatibilized biocomposites pellets for further compression/injection moulding. Such processing technique is of commercial importance. It is well documented that compression molding and injection molding processing are general methods used in manufacturing natural fiber reinforced composites. Mohanty et al. 2004, reported that injection molding will improve the fiber dispersion and hence increase tensile and flexural properties. On one hand, extrusion and injection molding has been reported to damage the properties of natural fibers as well as

traditional fibers, which result in changes in length and diameter distribution of the fibers. Consequently, the properties of the composite materials are affected (Carneiro & Maia 2000). In contrast, compression molding neither damages, nor changes fibre orientation during processing, which can help to preserves the isotropic properties of the composites and reduces the changes in physical properties that is derived from the molecule relaxation of the materials during usage. Similarly, the properties of the molded compressed composites are related to the consolidation of the composites, which depends on the processing conditions as well as the molder used in the processing. For instance, more pressure is transferred to the composite in a closed mold process than in a frame mold process (Liu et al. 2007).

Mechanical retting results in much shorter fibres, which, in extreme cases, could be disadvantageous for further processing (Mohanty et al. 2005). Besides the mechanical properties, the chosen retting procedure also affects the fibre morphology, their surface composition and properties (Bismarck et al. 2002; Aranberri-Askargorta et al. 2003) as well as their water uptake behavior (Stamboulis et al. 2000).

The structure, microfibrillar angle, cell dimensions and defects, and the chemical composition of the plant fibres are the most important variables that determine the overall properties of fibres (Mukherjee & Satyanarayana 1984; Satyanarayana et al. 1986). In general, the tensile strength and young's modulus of plant fibre increases with increasing cellulose content of the fibres. The orientation of the cellulose microfibrils with respect to the fibre axis determines the stiffness of the fibre. Plant fibres are known to be more ductile if the microfibrils have a spiral orientation to the fibre axis. Fibres are inflexible, rigid and have a high strength if the microfibrils are oriented parallel to the fibre axis (Flemming et al. 1995).

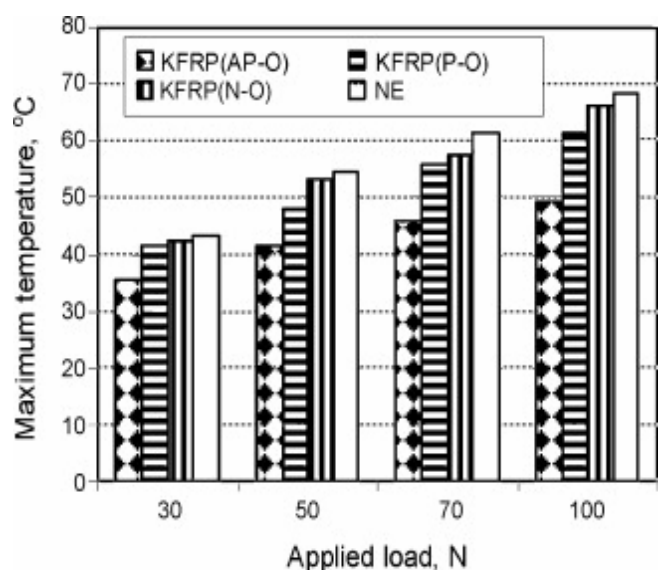


Fig 2 Interface temperature versus applied load (Chin & Yousif 2009)

(Chin & Yousif 2009), tested kenaf fibres as reinforcement for tribo-composite based on epoxy for bearing applications. Kenaf fibres reinforced epoxy (KFRE) composite was fabricated using a closed mould technique associated with vacuum system. Sliding wear and frictional behavior of the composite were studied against polished stainless steel counter face using Block-On-Disc (BOD) machine at different applied loads (30–100 N), sliding distances (0–5 km) and sliding velocities (1.1–3.9 m/s). The effect of the fibre orientations, with respect to the sliding direction, was considered; these orientations are parallel (P-O), anti-parallel (AP-O) and normal (N-O). The morphology of the worn surfaces of the composite revealed that the presence of kenaf fibres in the composite enhanced the wear and frictional performance of the epoxy and that applied load and sliding velocity have less effect on the specific wear rate of the composite in all the three orientations. The composite exhibited better wear performance in N-O compared to P-O and AP-O.

4.0 OVERVIEW OF MALAYSIAN CULTIVATED KENAF

In Malaysia, frantic effort have been made through the national kenaf research and development program to make kenaf an industrial crop especially since other commercially viable products can be derived from it. The government has therefore allocated

RM12m for research and further development of the kenaf-based industry under the 9th Malaysia Plan (2006–2010) in recognition of kenaf as a commercially viable crop (Edeerozey et al. 2007). So many research works had been conducted on Malaysian cultivated kenaf with a view to make kenaf an economically viable plant in Malaysia. Some of such work is the one done by (Ashori et al. 2006) and (Harun et al 2009). (Ashori et al. 2006) attempted to explore the chemical and morphological characteristics of kenaf cultivated in Malaysia and concluded that there are some significant similarities in fractions of kenaf and wood especially for its use in making printing paper.

Table 1 Composition of Everglades 71 kenaf-fibre variety (Ashori et al. 2006)

Fractions	Organic composition of fibres					Inorganic (ash content) (%)	Fibre length (Average) (mm)	Composition of Whole stem (%)
	Alpha cellulose (%)	Hemicellulose (%)	Pentosan (%)	Klason lignin (%)	Acid-soluble lignin			
Bast	56.4	26.2	13.4	13.4	1.3	2.2	2.48	34.3
stem	48.7	28.1	19	17.9	2.1	1.8	-	-
Core	46.1	29.7	20.7	19.8	2.3	1.6	0.72	65.7

Table 2 Fibre characteristics of kenaf fractions (Everglades 71) (Ashori et al. 2006)

Characteristics	Bast			Core		
	Average [Ⓜ]	Min & Max.	SD	Average ^{ⓂⓃ}	Min & Max	SD
Fibre length (L), mm	2.48	1.62-3.89	0.61	0.72	0.27-1.2	0.17
Fiber width (d), μm	24.24	12.17-47.85	6.92	31.88	10.69-55.84	8.64
Wall thickness (w), μm	4.85	16.5-12.68	1.57	4.08	0.58-11.50	1.68
Lumen width (l), μm	15.44	4.60-33.63	7.11	25.77	8.38-45.65	8.25
Runkel ratio (2w/l)	0.60	0.20-1.73	0.05	0.25	0.12-0.58	0.08
Felting factor (L/d)	104.83	52.93-183.10	29.86	24.36	10.15-69.32	10.43
Flexibility ratio (l/d)	63.87	36.60-83.25	9.39	80.03	63.40-89.24	4.88

[Ⓜ] Arithmetic (number) average, not compensated for fibre mass

^{ⓂⓃ} Coefficient of suppleness

Table 3: Mechanical properties of chemically retted and biologically retted Kenaf-Fibre (Harun et al. 2009)

Mechanical Properties	Chemically retted – [Vol. Fraction (%)]			Biologically retted – [Volume Fraction] (%)		
	40	50	60	40	50	60
Tensile stress (MPa)	134.86	172.20	197.10	176.64	223.20	232.35
Tensile modulus (GPa)	15.37	19.56	21.19	18.04	23.51	23.99
Flexural stress (MPa)	191.97	197.45	214.45	199.33	225.27	248.10
Flexural modulus (GPa)	13.51	13.82	16.11	13.49	15.71	18.49
Impact resistance (KJ/m ²)	35.18	87.22	65.70	41.74	77.87	76.71

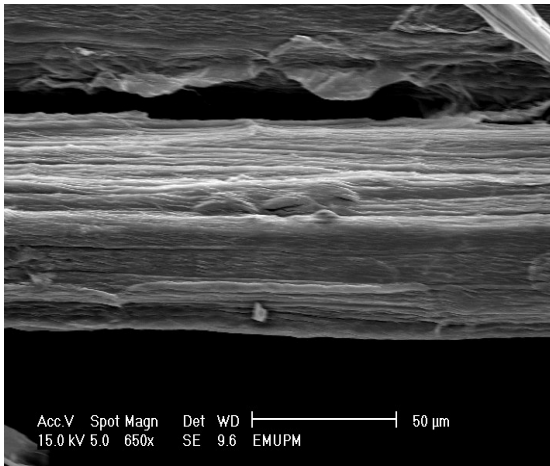


Fig3a. SEM of a chemically retted fibre

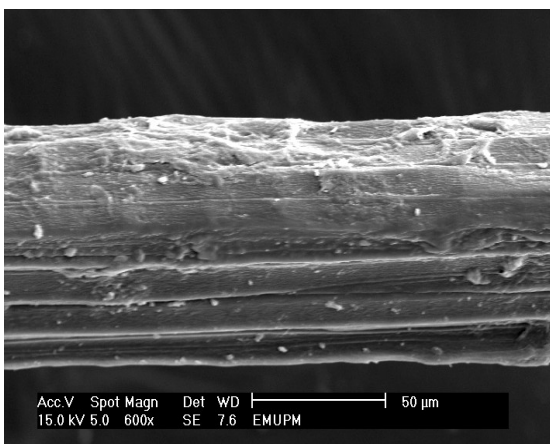


Fig 3b. SEM of a biologically retted fibre
(Khalina et al n.d.)

Kenaf variety explored by (Ashori et al. 2006) was “Everglades 71” collected from experimental field of MARDI. The data obtained from this variety clearly shows that it possessed high content of helocellulose and alpha-cellulose in its bast fibre which can contribute to better composite strength and stability. The morphology data obtained showed an indication of possible formation of a strong fibre-fibre hydrogen bond by virtue of easy pulp collapse, a property that is good for paper strength and may as well be of benefit to an effective strength between the OH-group of fibre surface with that of polymeric materials. Similarly, the fibre from bast have a large length to diameter ratio (104:8) resulting in flexible fibres that are good for fibre bonding and entanglement giving greater sheet, tear and tensile strength properties that are required in natural fibre composites.

(Harun et al. 2009) also highlighted some results obtained in the downstream sector of the on-going research in University putra Malaysia on some mechanical properties and came out with some agreeing features as (Ashori et al. 2006) on both chemically and biologically retted fibres. Most of the dimensions for the variety Everglades 71 presented by (Ashori et al. 2006) are also in conformity with that of kenaf variety (KB6 and V36) highlighted by Harun et al 2009. Khalina et al n.d. evaluated the tenacity of kenaf fibres and remarked that chemically retted fibres (138.82mN/tex) shows

lower tenacity value than the biologically retted ones (204.12mN/tex). These studies have all shown significant prospect of commercial viability and enhanced technological application of Malaysian cultivated kenaf for composite material production and other applications as well.

5.0 SUMMARY AND CONCLUSION

Good surface treatment will be required to properly combine hydrophilic fibre and hydrophobic polymer to produce composite with excellent properties. Kenaf, (*Hibiscus cannabinus*, L. family *Malvaceae*), a well known cellulosic source of fibre with economical and ecological advantages, exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability can be used in combination with PE after adequate treatment with silane which can help to greatly reduce the hydrophilicity of fibre for the production of such needed composite. Water solubility raises the degradability but on the other hand, in most cases, a water resistant material should be obtained for most application. Although the chemical structure of cellulose from all natural fibres is the same, there is a significant difference in their degree of polymerization and their mechanical properties are very much dependent on this. The higher the degree of polymerization of a particular type of fibre, the better composite it will be.

As reported by some authors, to achieve increase tensile strength, fibres to be used must show a higher tensile strength, young modulus and lower elongation than that of the polymer matrix. The tensile strength of the composite is proportional to the volume fraction of fibres assuming that the orientation of the fibres and the direction of the applied stress are parallel. Similarly, variation in mechanical properties of the composite depends on the climatic and growing conditions. Longer rod kenaf in this case provides better properties with fibres taken some few centimeters from the bottom providing better mechanical properties. It is important that critical fibre length be determined when preparing composite because below this critical length, mechanical and physical properties will be affected since it varies with fibre content i.e prevention of adequate transfer of load from the polymer to the fibre can be seen, as a result, composite can get damaged quite easily because of fibre pullouts. Depending on the fibre type, there is an optimal fibre content for which fibre-reinforced composites show the best properties and beyond this optimal fibre content, tensile strength decrease due to the increased presence of bubbles and voids in the composites. Critical fiber length for kenaf fiber reinforced biocomposites has been expressed around 6 mm. By compounding the fiber and polymer matrix/impregnation of the fibre with the matrix, the mixture can be extruded to varying degree of fiber loading with controlled extrusion temperature which can then be pelletized. The use of tools with large gates during extrusion and injection can provide better alternative to smaller gates to take care of higher fiber

loading which can reduce further rise in temperature. Air and water cooling of the extrusion can be explored to determine the one that will give better mechanical properties especially that the pellets produced will have to go through another temperature rise during injection molding. Pultrusion method is another alternative in improving mechanical properties of engineered materials and mechanical over straining of fibres during mechanical processing steps of the fibre separation can result in the formation of kink bands and splices which dramatically lower the tensile and compressive strength of fibres. Furthermore, retting of fibres is another critical issue and the starting point of maintaining optimum composite properties. Mechanical retting results in much shorter fibres, which, in extreme cases, could be disadvantageous for further processing. Besides the mechanical properties, the chosen retting procedure also affects the fibre morphology, their surface composition and properties as well as their water uptake behavior. The structure, microfibrillar angle, cell dimensions and defects, and the chemical composition of the plant fibres are the most important variables that determine the overall properties of fibres. In general, the tensile strength and young's modulus of plant fibre increases with increasing cellulose content of the fibres and the orientation of the cellulose microfibrils with respect to the fibre axis determines the stiffness of the fibre. Plant fibres are more ductile if the microfibrils have a spiral orientation to the fibre axis. Fibres are inflexible, rigid and have a high strength if the microfibrils are oriented parallel to the fibre axis. Polyethylene (PE) can provide a good fibre matrix adhesion with kenaf especially when maleated polyethylene (MAPE) is used as a compatibilizer. Since tensile and flexural stress increase with increase fiber content, while impact stress reduces with fiber loading, bast fibres that have very high tensile and flexural stress can be combined with fibres from leave that is known to have the advantage of high impact stress. Further study will be conducted on improving the mechanical properties of Kenaf/PE reinforced composite.

REFERENCES

- Abdelmouleh, M. S. Boufi, Belgacem, M.N. and Dufresne., 2007. Short natural-fibre reinforced polyethylene and natural rubber composites: Effect of silane coupling agents and fibres loading. *Composites Science and Technology*, 67(7-8), 1627–1639.
- Abe, K. & Ozaki, Y., 1998. Comparison of useful terrestrial and aquatic plant species for removal of nitrogen and phosphorus from domestic wastewater. *Soil Science and Plant Nutrition (Japan)*.
- Amaducci, S. Amaducci M.T. Benati R. and Venturi G., 2000. Crop yield and quality parameters of four annual fibre crops (hemp, kenaf, maize and sorghum) in the North of Italy. *Industrial Crops & Products*, 11(2-3), 179–186.
- Aranberri-Askargorta, I., Lampke, T. & Bismarck, A., 2003. Wetting behavior of flax fibers as reinforcement for polypropylene. *Journal of colloid and interface science*, 263(2), 580–589.
- Ashori, A., Harun J., Raverty W. and Yusoff M., Chemical and Morphological Characteristics of Malaysian Cultivated Kenaf (*Hibiscus cannabinus*) Fiber.
- Belgacem, M.N. & Gandini, A., 2005. The surface modification of cellulose fibres for use as reinforcing elements in composite materials. *Composite Interfaces*, 12(1), 41–75.
- Bismarck, A., aranberri-Askargorta I., Spronger J., Lampke T., Wielage B., Stamboulis A., Shenderovich I and Limbach H., 2002. Surface characterization of flax, hemp and cellulose fibers; Surface properties and the water uptake behavior. *Polymer Composites*, 23(5), 872–894.
- Brahmakumar, M., Pavithran, C. & Pillai, R.M., 2005. Coconut fibre reinforced polyethylene composites: effect of natural waxy surface layer of the fibre on fibre/matrix interfacial bonding and strength of composites. *Composites Science and Technology*, 65(3-4), 563–569.
- Carneiro, O.S. & Maia, J.M., 2000. Rheological behavior of (short) carbon fiber/thermoplastic composites. Part I: The influence of fiber type, processing conditions and level of incorporation. *Polymer composites*, 21(6).
- Cheremisinoff, N.P., 1997. *Handbook of engineering polymeric materials*, CRC.
- Chin, C.W. & Yousif, B.F., 2009. Potential of kenaf fibres as reinforcement for tribological applications. *Wear*, 267(9-10), 1550–1557.
- Colom, X., Carrasco F., Pages P. and Canavate J., 2003. Effects of different treatments on the interface of HDPE/lignocellulosic fiber composites. *Composites Science and technology*, 63(2), 161–169.
- Edeerozey, A.M. Akil H.M., Azar A.B. and Ariffin M.I.Z., 2007. Chemical modification of kenaf fibers. *Materials Letters*, 61(10), 2023–2025.
- Flemming, M., Ziegmann, G. & Roth, S., 1995. *Faserverbundbauweisen: Fasern und Matrices*, Springer.
- Foulk, J.A., Chao W.Y., Akin D.E., Dodd R.B. and Layton P.A., 2004. Enzyme-Retted Flax Fiber and Recycled Polyethylene Composites. *Journal of Polymers and the Environment*, 12(3), 165–171.

- George, J., Sreekala, M.S. & Thomas, S., 2001. A review on interface modification and characterization of natural fiber reinforced plastic composites. *Polymer Engineering & Science*, 41(9).
- Habibi, Y., El-Zawawi W.K., Ibrahim M.M. and Dufresne A., 2008. Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibers from Egyptian agro-industrial residues. *Composites Science and Technology*, 68(7-8), 1877–1885.
- Hambali A., Sapuan S.M., Ismail N. and Nukman Y. (2009). Composite manufacturing process selection using analytical hierarchy process; *International Journal of Mechanical and Materials Engineering*, Vol. 4, No. 1, University of Malaya, Malaysia
- Harun, J., Paridah Md. T., NorAini Abd. S. and Khalina Abdan, 2009; Kenaf- its establishment and journey towards energizing the wood-based and biocomposite industry in Malaysia; international conference on prospect of jute and kenaf as natural fibres, Dhakar-Bangladesh.
- [37] Hazira Wan W.M., An-Sariumiah, Moh'd A.M. and Norsaadah I. 2004. Treatment of Kenaf for LDPE-Kenaf composite; Proceedings of the third technical review meeting on the national kenaf research project, 25-26 May, Kota Bharu, Kelantan.
- Herrera-Franco, P.J. & Valadez-Gonzalez, A., 2005. A study of the mechanical properties of short natural-fiber reinforced composites. *Composites Part B*, 36(8), 597–608.
- Kawai, S., Ohnishi Y., Okudaira Y. and Zhang M., 2000. Manufacture of oriented fiberboard from kenaf bast fibers and its application to the composite panel. In *Intern. Kenaf Symp.* pp. 144–148.
- Keener, T.J., Stuart, R.K. & Brown, T.K., 2004. Maleated coupling agents for natural fibre composites. *Composites Part A*, 35(3), 357–362.
- Khalina A., Jalaluddin H., and Yeong H. Aw, Properties of kenaf (*Hibiscus Cannabinus L.*) Bast fibre reinforced unsaturated polyester composite; chapter in book: *Research in Natural fibre reinforced polymer composites*, 233-246.
- Lei, Y., Wu Q., Yao F. and Xu Y., 2007. Preparation and properties of recycled HDPE/natural fiber composites. *Composites Part A*, 38(7), 1664–1674.
- Li, Y., Hu, C. & Yu, Y., 2008. Interfacial studies of sisal fiber reinforced high density polyethylene (HDPE) composites. *Composites Part A*, 39(4), 570–578.
- Liu, W., Drzal L.T., Mohanty A.K. and Misra M., 2007. Influence of processing methods and fiber length on physical properties of kenaf fiber reinforced soy based biocomposites. *Composites Part B*, 38(3), 352–359.
- Liu, W., Misra M., Askeland P, Drzal L.T. and Mohanty A.K., 2005. 'Green'composites from soy based plastic and pineapple leaf fiber: fabrication and properties evaluation. *Polymer*, 46(8), 2710–2721.
- Lundin, T., Cramer M.S., Falk R.H. and Felton C., 2004. Accelerated weathering of natural fiber-filled polyethylene composites. *Journal of Materials in Civil Engineering*, 16, 547.
- Magurno, A., *Vegetal fibers in automotive interior components 1999*, 2nd International Wood and Natural Fibre Composites Symposium June 28-29, in Kassel/Germany
- Mohanty, A.K., Misra, M. & Drzal, L.T., 2005. *Natural Fibers, Biopolymers, and their Biocomposites*, CRC Press.
- Mohanty, A.K., Wibowo A., Misra M. and Drzal L.T., 2004. Effect of process engineering on the performance of natural fiber reinforced cellulose acetate biocomposites. *Composites Part A*, 35(3), 363–370.
- Mukherjee, P.S. & Satyanarayana, K.G., 1984. Structure and properties of some vegetable fibres. *Journal of Materials Science*, 19(12), 3925–3934.
- Nielsen, L.E. & Landel, R.F., 1994. *Mechanical properties of polymers and composites*, Marcel Dekker Inc.
- Nishino, T., Hirao, K. & Kotera, M., 2006. X-ray diffraction studies on stress transfer of kenaf reinforced poly (l-lactic acid) composite. *Composites Part A*, 37(12), 2269–2273.
- Nishino, T., Hiroa A.K., Kotera M., Nakamae K. and Inagaki H., 2003. Kenaf reinforced biodegradable composite. *Composites Science and Technology*, 63(9), 1281–1286.
- Ochi, S., 2007. Mechanical properties of kenaf fibers and kenaf/PLA composites. *Mechanics of Materials*.
- Pande, H. & Roy, D.N., 1998. Influence of fibre morphology and chemical composition on the papermaking potential of kenaf fibres: A look at what attributes affect tensile strength. *Pulp & paper Canada*, 99(11), 31–34.
- Panthapulakkal, S., Sain, M. & Law, S., 2005. Effect of coupling agents on rice-husk-filled HDPE extruded profiles. *Polymer International*, 54(1).

- Qiu, W., Zhang F., Endo T. and Hirotsu T., 2005. Isocyanate as a compatibilizing agent on the properties of highly crystalline cellulose/polypropylene composites. *Journal of Materials Science*, 40(14), 3607–3614.
- Ramaswamy, G.N., Craft, S. & Wartelle, L., 1995. Uniformity and softness of kenaf fibers for textile products. *Textile Research Journal*, 65(12), 765.
- Satyanarayana, K.G., Ravikumar K.K., Sukumaran K., Mukherjee P.S., Pillai S.G.K. and Kulkarni A.G., 1986. Structure and properties of some vegetable fibres. *Journal of Materials Science*, 21(1), 57–63.
- Sellers Jr, T., Reichert N.A., Columbus E., Fuller M. and Williams K., 1999. Kenaf properties, processing and products. Mississippi State University, MS.
- Shibata, S., Cao, Y. & Fukumoto, I., 2006. Lightweight laminate composites made from kenaf and polypropylene fibres. *Polymer Testing*, 25(2), 142–148.
- Stamboulis, A., Baillie C.A., Garkhail S.K., Van Melick H.G.H. and Peijs T., 2000. Environmental durability of flax fibres and their composites based on polypropylene matrix. *Applied Composite Materials*, 7(5), 273–294.
- Torres, F.G. & Aguirre, M., 2003. Rotational Moulding and Powder Processing of Natural Fibre Reinforced Thermoplastics. *International Polymer Processing*, 18(2), 204–210.
- Torres, F.G. & Cubillas, M.L., 2005. Study of the interfacial properties of natural fibre reinforced polyethylene. *Polymer Testing*, 24(6), 694–698.
- Torres, F.G. & Diaz, R.M., 2004. Morphological Characterisation of Natural Fibre Reinforced Thermoplastics(NFRTP) Processed by Extrusion, Compression and Rotational Moulding. *Polymers and Polymer Composites*, 12(8), 705–718.
- Van de Weyenberg, I., Ivens J., De Coster A., Kino B. Baetens E. and Verpoest I., 2003. Influence of processing and chemical treatment of flax fibres on their composites. *Composites Science and Technology*, 63(9), 1241–1246.
- Van Sumere, C.F., 1992. Retting of Flax with Special Reference to Enzyme-retting, in "The Biology and Processing of Flax," HSS Sharma and CF Van Sumere, Eds. M. Publications, Belfast, Northern Ireland, UK, 157–198.
- Wambua, P., Ivens, J. & Verpoest, I., 2003. Natural fibres: can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, 63(9), 1259–1264.
- Wolcott, M.P. & Smith, P.M., 2004. Opportunities and challenges for wood-plastic composites in structural applications. *Proceedings of Progress in Woodfibre-Plastic Composites-2004 Toronto, ON*.
- Young, R.A., 1997. Utilization of natural fibers: characterization, modification and applications. USP e UNESP, S. Paulo, 11.
- Zampaloni, M., Pourboghraat F., Yankovich S.A., Rodgers B.N., Moore J. Drzal L.T., Mohanty A.K. and Misra M., 2007. Kenaf natural fiber reinforced polypropylene composites: A discussion on manufacturing problems and solutions. *Composites Part A*, 38(6), 1569–1580.