KENAF/GLASS HYBRID COMPOSITES: PREPARATION, CHARACTERIZATION AND PROPERTIES

by

ABDUL MALEK YA'ACOB

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LIST OF ABBREVIATIONS

B727	Boeing 727
RMK9	Rancangan Malaysia Ke-9
E-GF	E – Glass fiber
CAIP	Civil Aircraft Inspection Procedures
CAAIP	Civil Aircraft Airworthiness Information and Procedures
MPa	Mega Pascal
GPa	Giga Pascal
MARDI	Malaysian Agricultural Research and Development Institute
MIAT	Malaysian Institute of Aviation Technology
UV	Ultraviolet
NaOH	Sodium hidroxide
H_2SO_4	Sulfuric Acid
MEK	Methyl Ethyl Ketone
FTIR	Fourier Transform Infrared
DSC	Differential Scanning Calorimetry
DMA	Dynamic Mechanical Analysis
SEM	Scanning Electron Microscopy
ASTM	American Society for Testing and Materials
Tg	Glass transition temperature
% wt	Percent by weight
ROM	Rules of mixture

LIST OF SYMBOLS

g	Gram
J	Joule
Kg	Kilogram
mm	Millimeter
kN	Kilonewton
N	Newton
T_g	Glass transition temperature
V_f	Volume fraction
W_f	Weight fraction
ρ_c	Composite density
ρ_f	Fiber density
ρ_m	Matrix density

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KOMPOSIT GENTIAN HIBRID KENAF/KACA: PENGHASILAN, PENCIRIAN DAN SIFAT-SIFAT

ABSTRAK

Kajian ini melibatkan penggunaan gentian kenaf panjang dan fabrik gentian kaca gred pesawat komersil serta potensinya dalam penghasilan komposit. Komposit gentian hibrid kenaf/kaca epoksi telah difabrikasi menggunakan gentian kenaf tidak dirawat dan dirawat. Rawatan kenaf telah dilakukan menggunakan natrium hidroksida dan kaedah pengasetilan untuk mengubahsuai permukaan gentian kenaf. Dalam kajian ini tiada pengubahsuaian dilakukan terhadap permukaan gentian kaca atau sistem matrik. Kajian ini menggabungkan gentian kaca umumnya digunakan pada pesawat dengan gentian kenaf menggunakan konsep hibrid antara lapisan. Kaedah fabrikasi yang telah digunakan untuk menggabungkan gentian kenaf dengan gentian kaca bagi menghasilkan komposit ialah kaedah pelapisan tangan dan pembalut vakum. Sampel hibrid kenaf dan gentian kaca yang telah dihasilkan untuk kajian ini memanfaatkan konsep orientasi dua arah, di mana satu lapisan gentian disusun pada arah 'weft' manakala gentian lapisan kedua disusun pada arah 'warp'. Pencirian dan kajian sifat-sifat sampel komposit gentian hibrid kenaf/kaca epoksi telah ditentukan melalui morfologi pelekatan, fizikal, termal dan mekanikal. Kelakuan mekanikal yang tidak konsisten untuk sampel komposit gentian kenaf tidak dirawat/kaca telah disahkan oleh kandungan rongga yang tinggi antara gentian dan matrik yang boleh mencecah sehingga 300% berbanding sampel dirawat. Komposit gentian kenaf dirawat/kaca menunjukkan konsistensi dalam ciri-ciri pelenturan

dan kekuatan hentaman pada peratusan berat gentian kenaf yang rendah iaitu pada 10% berat, 20% berat dan 30% berat kenaf.

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ABSTRACT

This research involved the use of long kenaf fiber and glass fiber fabric grade commercial aircraft and its potential to be used in composite production. Hybrid kenaf/glass fiber epoxy composites have been fabricated using untreated and treated kenaf. Kenaf treatment was done using sodium hydroxide and acetylation process to modify the surface of the kenaf fibers. In this study no modification was done on the surface of glass fibers or the matrix. This study combines glass fiber commonly used on aircraft with kenaf fiber using interply hybrids concept. The fabrication method that has been used to combine the kenaf and glass fiber to produce composite is hand lay-up and vacuum bagging method. Hybrid samples of kenaf and glass fiber produced for this study utilized the bidirectional orientation concept where one fiber layers is align in the 'weft' direction and the second fiber layers is align in the 'warp' direction. Characterization and study of the properties of hybrid kenaf/glass fiber composites was determined by morphological of adhesion, physical, thermal and mechanical. Inconsistent mechanical properties behavior for untreated kenaf /glass fiber composites samples was confirmed by the high void content between fiber and matrix that can reach up to 300% with comparison to treated samples. Kenaf fiber treated/glass composites showed a consistency in bending characteristics and impact strength at low percentage by weight of kenaf fiber namely at 10 wt%, 20 wt% and 30 wt% kenaf.

CHAPTER 1

INTRODUCTION

1.1 Overview on Kenaf Bio-composites

The commonly known driving forces of doing research on natural fibers reinforcement generally in Malaysia are cost reduction with comparison to fibers such as glass and carbon fiber, weight reduction for final products and the potential market for renewable materials and recycle materials. In terms of renewable sources, kenaf also known as short term plant that produces at least 15 to 20 tones metric of bast fiber per hectare in Malaysia (Mahmud, 2001). According to Sharifah and Martin (2004), kenaf are biodegradable and environmentally friendly crops whereby the most rapidly expanding application for kenaf is composites reinforcement. The idea of fabricating a composites structure that utilizes kenaf fiber as the reinforcement phase is also due to the effort made by the government of Malaysia in 9th Malaysia Plan (RMK9, 2009) to replace the tobacco plant with kenaf (*Hibiscus cannabinus* L.).

Natural fibers such as kenaf, flax, jute and hemp are the most common reinforcement used to produce bio-composites component recently. All natural fibers are categorized base on Fig. 1.1.

Many of recent works focused on kenaf bio-composites study to develop components specifically in non-structural application such as commercial consumer products, automotive industries and building interior construction.

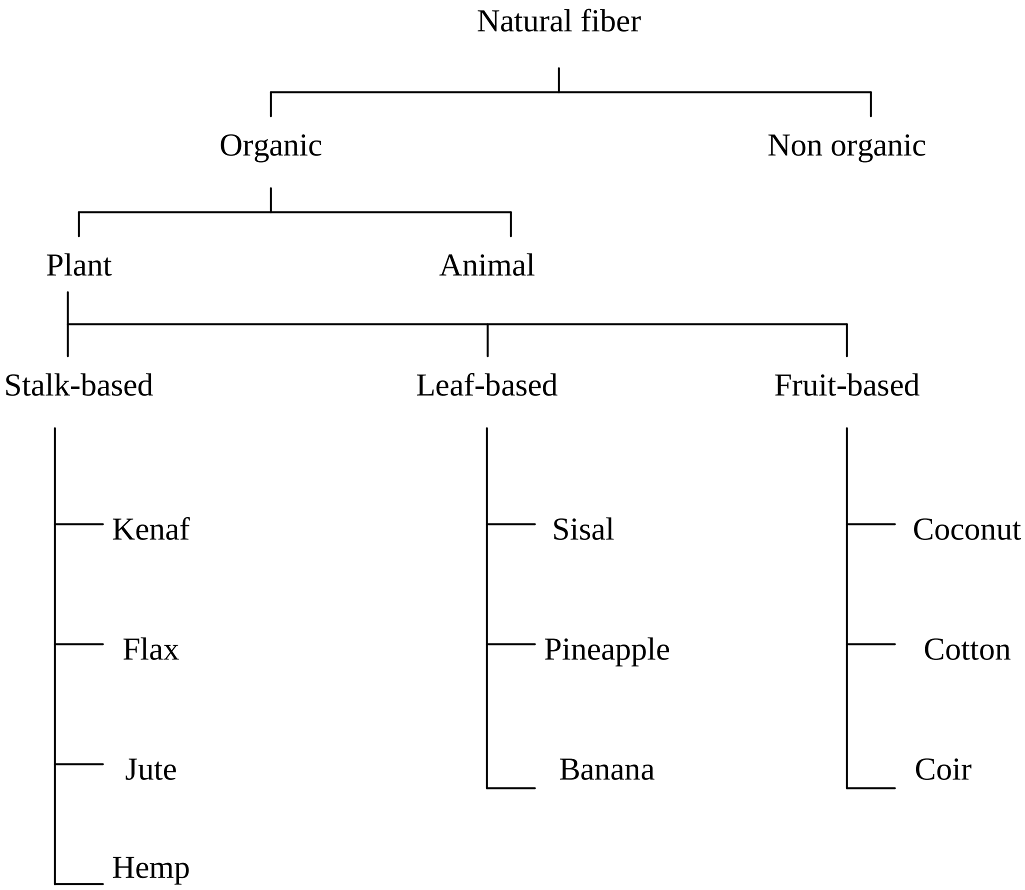


Fig. 1.1: Type of natural fiber (George, 2008)

Ramaswamy et al. (2003) blended kenaf fibers with polypropylene, Khristova et al. (2002) used core and bark pulps, Shinji (2008) fabricated kenaf/PLA biodegradable composites, Shibata et al. (2005; 2006) fabricated kenaf/corn starch composites using press forming method and kenaf/polypropylene lightweight laminate composites, Sharifah and Martin (2004) used hot press fabrication of long and random kenaf/polyester composites, Takashi et al. (2003) produced kenaf/PLLA composites, Huda et al. (2008) used compression moulding of kenaf/PLA laminated composites.

Liu et al. (2007) fabricated kenaf/soy biocomposites by extrusion, injection and compression molding, Rouison et al. (2004) manufactured hemp/kenaf/polyester bio-composites using resin transfer molding and Guzman et al. (1982) blended kenaf/polyester to produced non woven fabrics using calendaring, melt blowing and spun bonding. Hence, several attempts have been made to use natural fibers as replacement for fiber glass mostly in non structural applications (Wambua et al., 2003).

However the drawback with regards to mechanical, physical and thermal properties of kenaf fibers used in this study are generally influenced by the climate, the growth condition, the planting location and soil. Hence, the kenaf bio-composites properties are also affected by the fiber processing stages which include retting and fiber surface treatment. However, the issues on high moisture absorption prevented a more advance potential application of kenaf bio-composites. Natural fibers have high level of moisture absorption, poor wettability and insufficient adhesion leading to debonding with age (Gassan, 2002). Thus in this study, certain mechanical behavior of the kenaf bio-composites are still poorly understood due to reasons stated above.

1.2 Problem Statement

In the past, the potential advantages of composites material were not fully realized (Bannister, 2001). In Malaysia however, there has been significant interest in the development of natural fibers bio-composites to replace synthetic fibers. Due to high demand in finding substitute reinforcement material for conventional composites, researches are turning into natural fibers which posses the same mechanical properties as the synthetic reinforcement with increase in toughness, lower cost and less environmental effects. According to Mishra et al. (2003), biocomposites are mainly price-driven commodity composites that have useable structural properties at relatively low cost. Study by Sharifah and Martin (2004), stated that conventional composites using synthetic fiber resulted in environmental effects, hazardous and disposable problems. Takashi et al. (2003) and Huda et al. (2008) findings shows that carbon fibers, glass fibers and petroleum based plastics causes environmental problems in disposal by incineration. Hence, the future demands for commercial exploitation of bio-composites are due to global community pressure to reduce environmental impact, weight and cost (George, 2008).

The work presented in this study concerns the use of long kenaf bast fibers as a potential reinforcement when combining with fabric form synthetic fibers in polymer composites. The common advantages of kenaf fibers composites with comparison to synthetic fibers composites are environmental friendliness, lower cost hence reducing the production cost of composites end product, renewable resources with regards to fiber reinforcement materials, lower density with regards to composites application and healthier working environment with regards to processing stages. As proof of demand and interest towards Malaysian kenaf bio-composites, articles published by Malaysia Agricultural Research Development Institute (MARDI) and Malaysian Tobacco Board in recent years showed the vast potential of kenaf fibers for Malaysia (Jalaluddin, 2001). However, the full potential of kenaf/glass fiber epoxy composites kenaf is directed towards low end application rather than high end application.

1.3 Objective

Several objectives are listed as follows with regards to this study;

a) To fabricate a composites sample base on interply of kenaf/glass fiber epoxy hybrid using hand lay up and vacuum bagging method.

b) To study the physical, thermal and mechanical properties for hybrid unidirectional kenaf/glass fiber epoxy composites.

c) To study the morphology of adhesion through fractured tensile surface for treated and untreated kenaf/glass fiber epoxy composites.

d) To compare the thermal and mechanical properties for fabricated composite samples with B727 glass fiber epoxy sandwich commercial sample.

CHAPTER 2

LITERATURE REVIEW

2.1 Preliminary Studies on Typical Natural Fibers Reinforced Composites

Currently, research in composite materials is being directed towards using natural fibers instead of synthetic fibers. Conventional fiber reinforced composites are composed of carbon fibers, glass fibers which are incorporated into unsaturated polyester or epoxy resin that show high mechanical and thermal properties but causes environmental problems in disposal (Takashi et al., 2003).

Natural fiber contributes to the new development of composites structures especially in the automotive industries. The natural fiber composites parts offer low density, low cost, environmentally harmless and good mechanical properties (Shibata et al., 2005; 2008). Natural fibers is renewable resource, less dense, cheaper, maybe recycled, act as reinforcing fibers in thermoplastic and thermoset matrix composites thus providing environmental benefits with respects to ultimate disposability and raw material utilization (Sharifah and Martin, 2004). According to Wambua et al. (2003), natural fibers are about 50% lighter than glass, generally cheap and natural fibers composites are renewable. Study by Voorn et al. (2001) showed that, natural fibers reinforced composites (NFRC) exhibit several advantages compared to glass fiber reinforced composites (GFRC) such as low density and low equipment ware and are relatively cheap and are obtained from renewable resources.

Hence, European legislation on waste dumping stated that natural fiber reinforced composites exhibit the advantage of being combustable (Voorn et al., 2001). Based on arguments mentioned above, it is clearly showed that in general natural fibers are biodegradable and environmentally friendly.

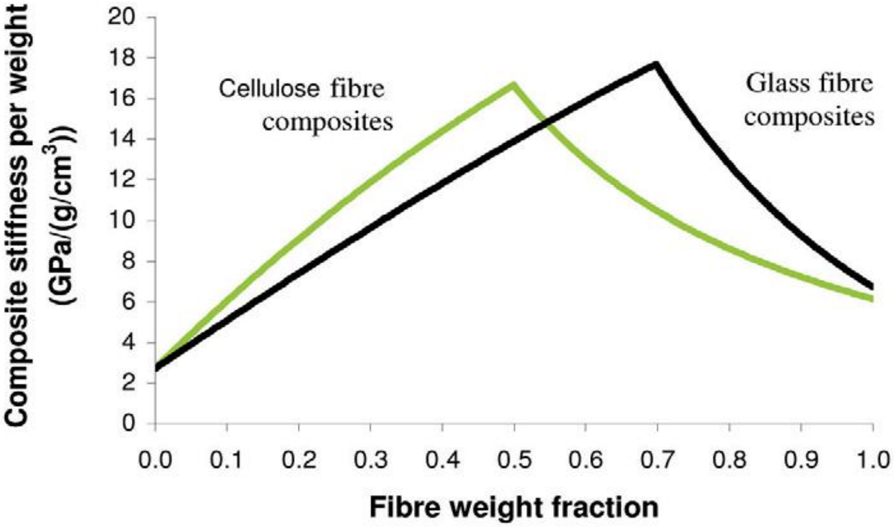
2.2 General View on Natural Fibers Reinforcements

Natural fibers refers to fibers that are extracted from plants and classified into three categories depending on the part of the plant where they are extracted from which are listed below (Mohanty et al., 2005);

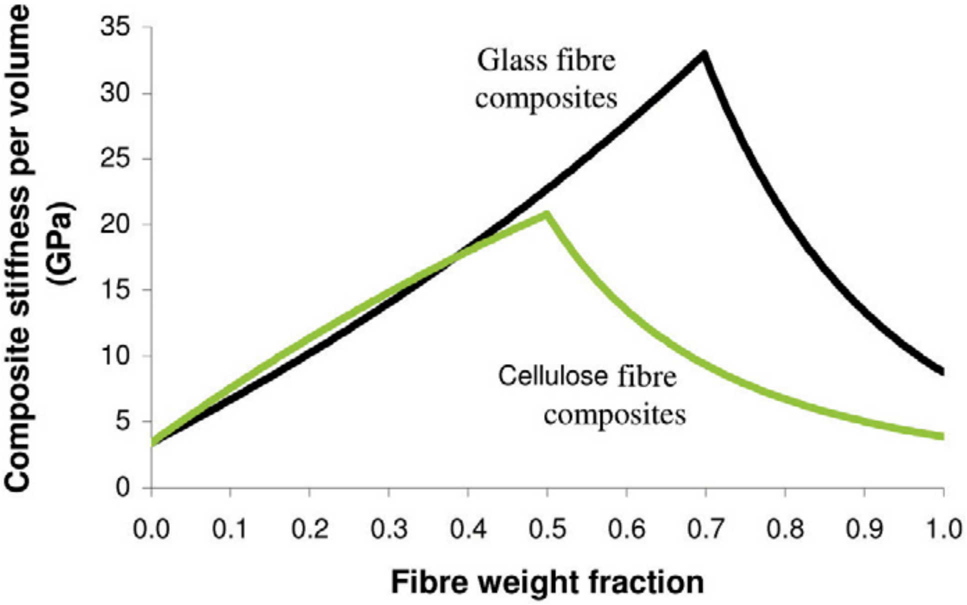
a) Fruit fibers that are extracted from the fruits of the plant where they are light and hairy forms.
b) Bast fibers that are found in the stems of the plant.
c) Fibers that are extracted from the leaves that is rough and sturdy.

According to Mohanty et al. (2005), the drawback of natural fiber are the properties of natural fiber raw products that are strongly influenced by their growing environment, temperature, humidity, the composition of the soil and the air that eventually will effects the height of the plant, strength of its fibers and density of fiber. Procedures of harvesting and processing the natural fibers will also resulted in a variation of end properties. Generally natural fibers have hollow space (the lumen) as well as nodes at irregular distances that divide the fiber into individual cells. However, one of the best criteria of natural fibers is the surface of natural fibers is rough and uneven thus providing good physical adhesion to the matrix in a typical composite structure. In addition, thin natural fibers with a large surface to volume ratio resulted in good adhesion between the fibers and the matrix (Mohanty et al., 2005).

According to George (2008), the generalized properties for natural fiber include having density of 1.5 g/cm^3, strength of 300 to 900 MPa and stiffness of 30 to 70 GPa with comparison to glass fiber that have density of 2.6 g/cm^3, strength of 3500 MPa and stiffness of 70 GPa. Fig. 2.1 shows natural fiber composites have lower stiffness per volume, higher stiffness per weight and higher stiffness per cost. Hence, as a result natural fiber needed larger volume for composites material.

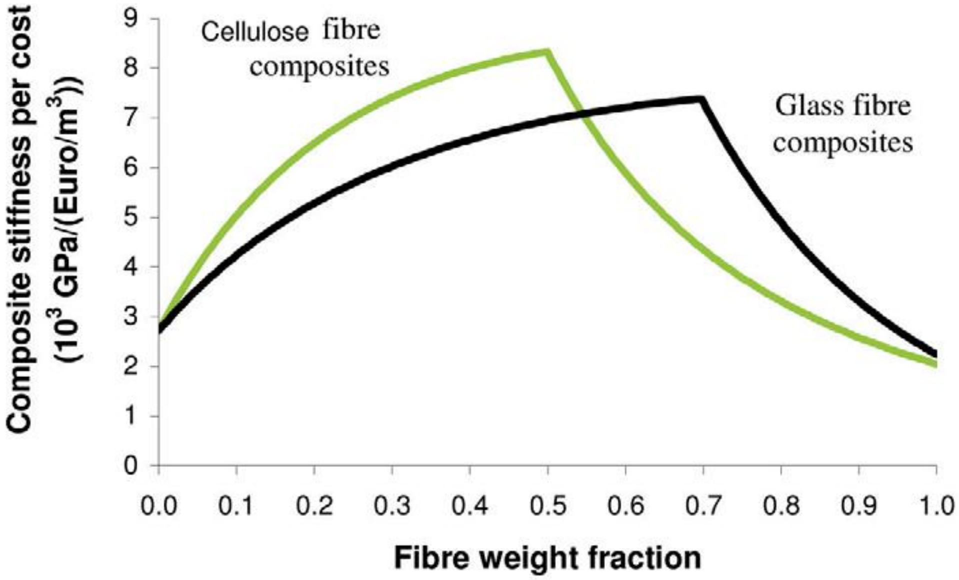


(a)



(b)

Fig. 2.1: Bio-composites comparison with glass fiber composites; (a) stiffness (per volume), (b) stiffness (per weight) and (c) stiffness (per cost) (George, 2008)



(c)

Fig. 2.1. Continued

2.3 Advantages and Disadvantages of Natural Fibers Reinforcement

Several advantages and diadvantages of natural fiber composites are summarized as shown in Table 2.1 (Mohanty et al., 2005);

Table 2.1: Natural fibers properties

Advantages	Disadvantages
Renewable material	Moisture absorption
Can be thermally recycled	Fluctuation in quality, price and availability (fluctuate by harvest results or agricultural)
Give less problem concerning health and safety of workers	Dimension instability
Less abrasive to machine during processing	Susceptibility to rotting
Good thermal and acoustic properties	

Table 2.1. Continued

Advantages	Disadvantages
Excellent price performance.Natural fibers are cheap and have a better stiffness per weight than glass which results in lighter components Low specific weight which results in higher specific strength and stiffness than glass Producible with low investment at low cost which makes the material an interesting product for low-wage countries Friendly processing which means no wear of tooling and no skin irritation Light weight depended on end product Low-energy production hence reducing the greenhouse effect.	Swelling leads to micro-cracking Restricted processing temperature Smell of natural fibers when process at high temperature Lower strength properties particularly its impact strength Poor fire resistance whereby natural fibers must be worked at low temperatures at approximately 350°C and below.

2.4 Material Overview

2.4.1 Kenaf fiber

According to Preston (2003), kenaf grows quickly, rising to heights of 12 to 14 feet in 4 to 5 months. It has been used for thousands of years in Africa and parts of Asia as a source of fiber for making clothing, rugs, rope and other products, as well as a source of food. Kenaf is an annual herbaceous plant cultivated for the soft bast fiber in its stem and has a relatively wide range of adaptation to climate and soils. Kenaf’s stems produce two types of fibre, a coarser fiber in the outer layer, and a finer fiber in the core and mature in 100 to 125 days (Preston, 2003). Takashi et al. (2003) reported that kenaf fibers can be a good candidate for the reinforcement fiber of high performance biodegradable polymer composites, as a cellulosic source with economical and ecological advantages, exhibits low density, non abrasiveness during processing, high specific mechanical properties and biodegradability. Sharifah and Martin (2004) in their work reported that base on the differential thermal analysis curves of untreated hemp and untreated kenaf fibers, findings shows that kenaf fiber is more thermally stable as its first decomposition temperature occurs at 297°C whereas for hemp its first decomposition temperature occurs earlier at 255°C. According to Jalaludin (2001), the high amount of holocellulose in kenaf fibers especially bast fibers indicates its suitability as a source of fibers for the pulp manufacturing process. In addition, study has been done in MARDI, Serdang to estimate the overall cost of production for dried kenaf whereby 5.67 tonnes of wet kenaf is equal to 1 tonne of dried kenaf or RM 396.90 per tonne of fibers (Mahmud, 2001). Table 2.2 showing inputs from study at Veterinary Institute, Kluang, Malaysia on 25 acres of land and fiber cost comparison respectively. However, the cost of producing kenaf for fiber is lower than for fodder because there is no drying cost for air dried kenaf.

Table 2.2: Estimated cost for kenaf fiber in Malaysia (Mohd, 2003)

Cost of producing kenaf for fibre	RM / kg
Farm cost (Yield of 75t/ha fresh or 17.3 t/ha dry)	0.17
Air dry cost	0.00
Total cost of producing air dried kenaf	0.17

The cost of producing Malaysian dried kenaf in Table 2.2 is cheaper with comparison to cost estimated in Table 2.3. Study by Zampaloni (2007) provides evidence with regards to weight, performance and cost of kenaf/ polypropelene which is better compared to hemp/polypropelene and flax/polypropelene composites as shown in Table 2.3. In addition, study by Mohanty et al. (2005) shows mechanical properties comparison for different type of fibers in Table 2.4.

Table 2.3: Typical density of glass and kenaf fiber (Zampaloni, 2007)

Fiber	Density (g/cm³)	Cost (per kg USD)
Flax	1.40 – 1.50	0.40 – 0.55
Hemp	1.48	0.40 – 0.55
Jute	1.30 – 1.45	0.40 – 0.55
Sisal	1.45	0.40 – 0.55
Ramie	1.50	0.44 – 0.55
Cotton	1.50 – 1.60	0.44 – 0.55
Coir	1.15	0.40 – 0.55
Kenaf	1.40	0.40 – 0.55
E-glass	2.50	2.00
S-glass	2.50	2.00

Table 2.4: Characteristic values for the density, diameter and mechanical properties of fibers (Mohanty et al., 2005)

Fiber	Density (g/cm³)	Diameter (µm)	Tensile Strength (MPa)	Young's Modulus (GPa)
Flax	1.50	40 – 600	345-1500	27.6
Hemp	1.47	25 - 500	690	70
Jute	1.30 -1.49	25 - 200	393-800	13 -26.5
Kenaf	-	-	930	53
Ramie	1.55	-	400-938	61.4 -128
Nettle	-	-	650	38
Sisal	1.45	50 - 200	468-700	9.4 -22
PALF	-	20 - 80	413-1627	34.5-82.5
Abaca	-	-	430-760	-
Oil Palm EFB	0.7-1.55	150 - 500	248	3.2
Oil Palm mesocarp	-	-	80	0.5
Cotton	1.5 – 1.6	12 – 38	287 – 800	5.5 - 12.6
Coir	1.15 - 1.46	100 – 460	131 – 220	4 – 6
E- glass	2.55	< 17	3400	73
Kevlar	1.44	-	3000	60
Carbon	1.78	5 – 7	3400 – 4800	240 - 425

2.4.2. Epoxy resin

Epoxy resins have been used since 1927 and the first synthesis of resins occurred in 1936 to the point where it would become commercially applicable. Epoxy is used in this study due to good argument given by Rong et al. (2001) that stated the interfacial interaction either outside or inside acetylated sisal fiber bundles in the presence of epoxy is stronger. This is due to, the obstruction to cell pull-out and microfibril stretching exerted by epoxy sticking to the cell walls is much more severe and the increased strength of acetylated sisal is completely shielded (Rong et al., 2001).

There are many different types of resin in use in the composite industry. The majority of composites structural parts are made with three main types namely polyester, vinyl ester and epoxy. Epoxies however, out perform most other resin types in terms of mechanical properties and resistance to environmental degradation which leads to their almost exclusive use in aircraft components. The simplest epoxy is a three member ring structure known by the term ‘alpha-epoxy’ or ‘1,2-epoxy’. Epoxy resins are formed from a long chain molecular structure with reactive sites at either end. In the epoxy resin system, epoxy groups form these reactive sites. The epoxy molecule also contains two ring groups at its centre which are able to absorb both mechanical and thermal stresses therefore giving the epoxy resin very good stiffness, toughness and heat resistant properties. Fig. 2.2 below shows the typical chemical structure of an epoxy. The advantages and disadvantages of epoxy are listed in Table 2.5.

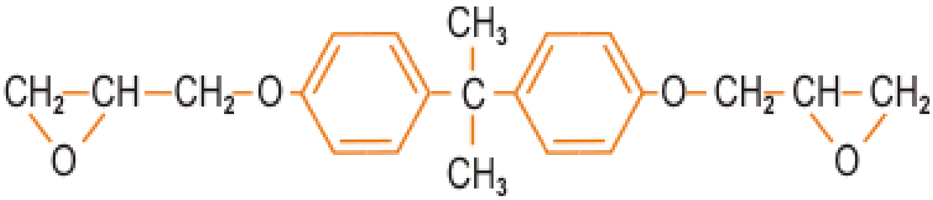


Fig. 2.2: Idealized chemical structure of a typical epoxy (Lee and Neville, 1982)

According to Mohanty et al. (2005), the requirement for a resin system for fabrication of natural fiber composites should follow the following characteristics;

a) Resin should provide good impregnation to allow all fibers to act as a single composites construction thus producing higher load composite capabilities. The matrix should have adequately low viscosity to ensure good impregnation of the reinforcing fibers.
b) The moisture content of resin should be controlled where post processing of natural fibers already contains a significant amount of water.
c) Fabrication stage should be based on the allowable processing temperature requirement for typical natural fibers.
d) The resin system should not damage the natural fibers and provides good adhesion to the natural fibers surfaces.

Table 2.5: Advantages and disadvantages of epoxy (Lee and Neville, 1982)

Advantages	Disadvantages
Higher durability, low porosity and strong bond strength Epoxies will harden in minutes or hours and several days to be completely cured. Epoxy resins are easily and quickly cured at any temperature from 5°C to 150°C, depending on the choice of curing agent Special epoxy formulations increased chemical resistance, increased temperature resistance, the ability to be applied underwater, and enhance resistance to yellowing and UV damage Underwater epoxies generally have excellent adhesion to most submerged surfaces Low viscosity and easily processed systems High electrical insulation	Expensive and more costly than polyester and vinyl ester Hazardous that causes cancer due to epichlohydrin (eyes, nose, skin and throat irritation) Critical in mixing ratio where wrong mixing will affect the final properties after cure and effect the matrix pot life

2.4.3 Glass fiber

E-glass fiber is used in this study due to its chemical composition that provides excellent electrical insulator and used for high end applications such as aircraft radome and aircraft cabin interior parts. Glass fiber is also the most economical reinforcement for composites and offers sufficient strength in most applications at a relatively low cost. The composition for glass is at least 50 percent silica oxide and another 50 percent consist of oxides of aluminum, boron, calcium and other compounds including limestone, fluorspar, boric acid and clay. The general comparison between natural fiber and glass fiber is shown in Table 2.6.

Table 2.6: Typical differences between glass and natural fibers (George, 2008)

Material Characteristics	Natural fibers	Glass fibers
Density	Low	Twice that of natural fibers
Cost	Low	Higher
Renewable	Yes	No
Recyclable	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO2 neutral	Yes	No
Abrasion to machine	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

2.5 Fundamental of Hybrid System

Hybrid system is generally a mixture of two or more different reinforcing fiber to provide higher composite strength, flexibility and durability. Hence, composites may utilize different combination of reinforcing fiber as follows;

a) Unidirectional.
b) 0/90 degrees orientation (woven, stitched or hybrid).
c) Random orientation.

However, the concept of the hybrid is to get a good characteristic for certain part or structure, maximizing the performance thus minimizing the weaknesses of the structure. The hybrid concept is also to reduce the cost of the structure as well as to maintain high strength and acceptable characteristic as same as by using an expensive material.

2.6 Composites Fabrication and Defects

Fabrication process plays a significant effect towards the end samples mechanical properties. Suggested method to incorporate resin into natural fibers has been practiced such as fabrication of laminate from kenaf fibers and polypropylene by using press forming (Shibata et al., 2005) and fabrication of sisal, kenaf, hemp, jute and coir and polypropylene composites by using compression moulding utilizing film stacking sequence (Wambua et al., 2003). Voorn et al. (2001) uses compaction rolling to fabricate the composites. However, finding shows the maximum impregnation of resin and fibers is utmost important to make sure that contact and interaction between fibers and resin are able to transfer the applied forces to the fibers most optimally. According to Horrocks and Subhash (2000), the basic composites mechanics begins with the assumption of a strong bond between matrix and fiber thus enable good load transfer from the matrix into the fibers. However, several possibilities of defects can be found generally during the fabrication process such as voids, air bubbles, high moisture content due to water ingression, dented, poor resin, rich resin, contamination, un even surfaces of which are basically refers back to the composites fabrication stages.

2.7 Fundamental of Vacuum Bagging Method

This process is basically an extension of the wet lay up process where pressure is applied to the laminate once fiber laid up has been completed in order to improve its consolidation and solidification. This is achieved by sealing a plastic nylon film over the wet laid up laminate and the samples mold tool. The air under the bag is extracted by a vacuum pump up to one atmosphere in order to consolidate the resin throughout the laminate. Hence, curing stages of a samples using vacuum bagging will progress rapidly due to closed environment and continous compression to the composites laminate. Listed below are all reasons for the utilization of vacuum bagging methodology with regards to kenaf/glass fiber epoxy samples preparation.

a) Better uniformity of lay up.
b) Stronger finished product.
c) Better strength to weight ratio.

Common materials and jigs used for vacuum bagging procedures are shown in Table 2.7 and Fig. 2.3.

Table 2.7: Vacuum bagging material (Foreman, 2001)

Material	Functions
Peel-ply	Providing textured and clean surface for lamination.
Bleeder cloth	Absorbing excess resin from the laminate.
Breather cloth	Providing gas flow path over the laminate both to permit the escape of air, moisture and volatiles and to ensure uniform vacuum pressure across the component.
Release film	Perforated sheet of material placed between the laminate and the mould surfaces to prevent adhesion.
Bagging film	Membrane which permits a vacuum to be drawn within the bag.
Vacuum pump	High-volume vacuum pump to vacuum out air
Pressure gauges	Clock-type gauges attached via a breach unit connection to monitor the pressure level.

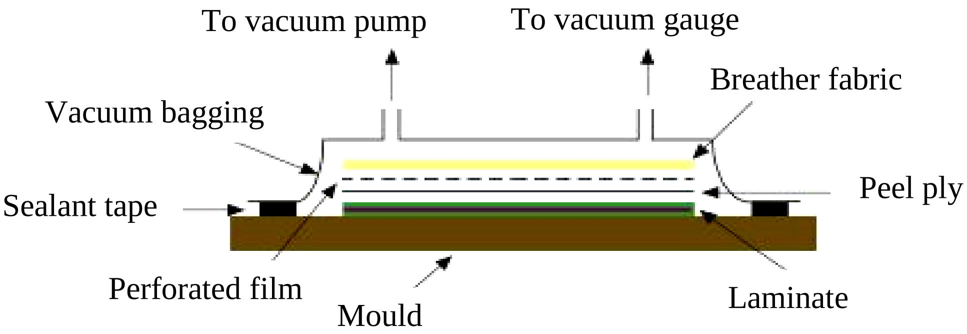


Fig. 2.3: Common materials for surface bagging (Foreman, 2000)

2.8 Chemical Modifications to Kenaf Fiber Surfaces

It is known that the difficulties in using natural fiber for fabrication of composites are the lack of good chemical adhesion to matrices (Rong et al., 2001, Wambua et al., 2003, Khalil and Rozman, 2004, Mohanty et al., 2005, Vilay et al., 2008 and John et al., 2008). In general, cellulose fibers are highly polar which makes them incompatible with non polar polymers. Hydrophilic nature of the natural fiber affects the adhesion to the hydrophobic nature of the matrix system resulting in poor strength properties. As such, the natural fiber surface is treated in order to promote adhesion prior to using the fiber as reinforcements for composites. Surface treatment produces a strong adhesion at the interface thus allowing good stress transfer and load distribution. Improvement of the interface via surface treatments resulted in good mechanical bonding with the matrix. According to Khalil and Rozman (2004), chemical treatment is the method to increase the wettability of the fiber-matrixs. Natural fiber that is treated using NaOH resulted in an increase in wettability, higher distribution of fibers inside matrix and minimum isolation of fiber-matix hence higher mechanical properties. NaOH treatment removes the tilosis and cutikel for the fiber surfaces and produces a rough fiber surfaces. Study done by Rong et al. (2001) shows that all chemical treatments resulted in greater extensibility and lower modulus thus related to the structural variation in the ultimate cells, resulted in swelling and partial removal of lignin and hemicellulose. According to Rong et al. (2001), the pretreatment of the natural fiber resulted in chemical and structural changes not only on the fiber surface but also in the distinct cells hence in turn influences the properties of the fibers and composites. The chemical methods bring about an active surface by introducing some reactive groups and provide the fibers with higher extensibility through partial removal of lignin and hemicellulose (Rong et al., 2001)

Mechanical properties and better performance of natural fiber composites are dependent on the interfacial compatibility between the matrix and the fiber surface. The most important factor in obtaining good fiber reinforcement for composites is the strength of adhesion between fibers and matrix (Alvarez and Analia, 2006). There are several methods that can be utilized to increase the compatibility of the fiber-matrix system. Commonly used methods are using alkaline solution such as sodium hydroxide, potassium hydroxide and lithium hydroxide. The main purpose of using an alkaline solution for treatments is to removes the plants wax components, removal of volatile products and to reduce the cementing material (Mohanty et al., 2005) According to Weyenberg et al. (2005), the removal of impurities and waxy substances from the fiber surface and creation of rougher surface promoted the mechanical interlocking and interface quality. Alkaline treatment that uses NaOH shows that sodium molecules have a favorable diameter and able to widen the smallest pores in between lattice planes and penetrate into them and resulted in high swelling (Weyenberg et al., 2005).

According to Mohanty et al. (2005), the major components of most plant fibers is cellulose, consisting of D-anhydroglucose ($C_6H_{11}O_5$) repeating units that are joined by ß-1,4-glycosidic linkages. Each repeating units contains three hydroxyl groups (OH group) where these groups contribute to the crystalline packing and the physical properties of cellulose materials that is shown in Fig. 2.4 and Table 2.8. In addition, according to Zampaloni (2007), natural fibers are mainly composed of cellulose that consist of three hydroxyl (-OH) groups and form intra-molecular and inter-molecular bonds causing vegetable fibers to be hydrophilic.

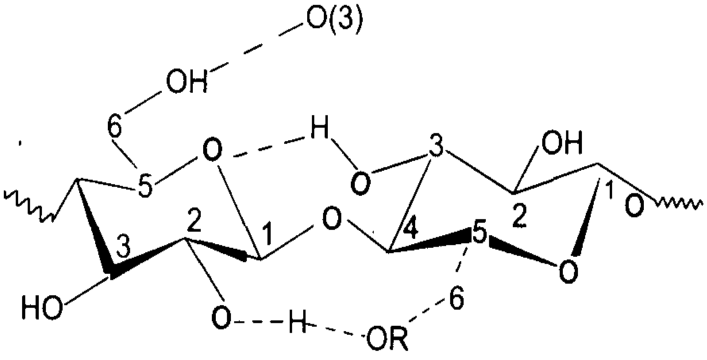


Fig. 2.4: Schematic drawing of cellulose molecules (Mohanty et al., 2005)

Zampaloni (2007) also stated that fiber treatment using alkaline solution dissolved unwanted microscopic pits or cracks on the fibers resulting in better fiber-matrix chemical adhesion. According to Mohanty et al. (2005), the surface modification of natural fibers not only decreases the moisture absorption but increase the wettability of the fibers by the matrix thus increases the interfacial bond strength. Fig. 2.5 shows the cell structure of natural fiber where cellulose microfibrils are embedded in lignin and hemicellulose matrix. According to Rong et al. (2001), fiber treatment of the fibers resulted in chemical and structural changes within the cell and fiber surface and hence altered the properties of the fibers and composites.

In addition, according to Mohanty et al. (2005) natural fibers are multi-cellular structure consisting of a number of continuous cylindrical honeycomb cells. These cells are cemented together by an intercellular substance which is isotropic, non-cellulosic and ligneous in nature as shown in Fig. 2.6.

Table 2.8 shows chemical composition, moisture content and microfibrillar angle of vegetables fibers

Table 2.8: Properties of natural fibers (Mohanty et al., 2005)

Fiber	Cellulose (%wt)	Hemicelluloses (%wt)	Lignin (%wt)	Pectin (%wt)	Moisture content (%wt)	Waxes (%wt)	Microfibrillar angle (deg)
Flax	71	18.6–20.6	2.2	2.3	8-12	1.7	5-10
Hemp	70-74	17.9-22.4	3.7-5.7	0.9	6.2-12	0.8	2-6.2
Jute	61-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5	8
Kenaf	45-57	21.5	8-13	3-5	-	-	-
Ramie	68.6-76.2	13.1-16.7	0.6-0.7	1.9	7.5-17	0.3	7.5
Sisal	66-78	10-14	10-14	10	10-22	2	10-22
PALF	70-82	-	5-12.7	-	11.8	-	14
Cotton	85-90	5.7	-	0.1	7.85-8.5	0.6	-
Coir	32-43	0.15-0.25	40-45	3-4	8	-	30-49

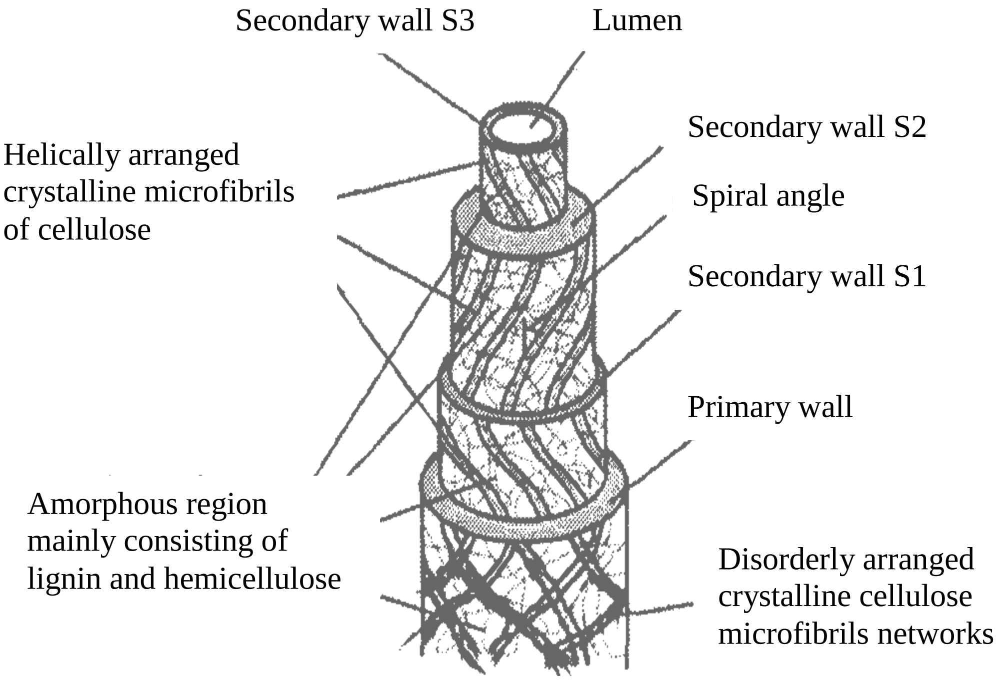


Fig. 2.5: Structural constitution of a natural vegetable fiber cell (Rong et al., 2001)

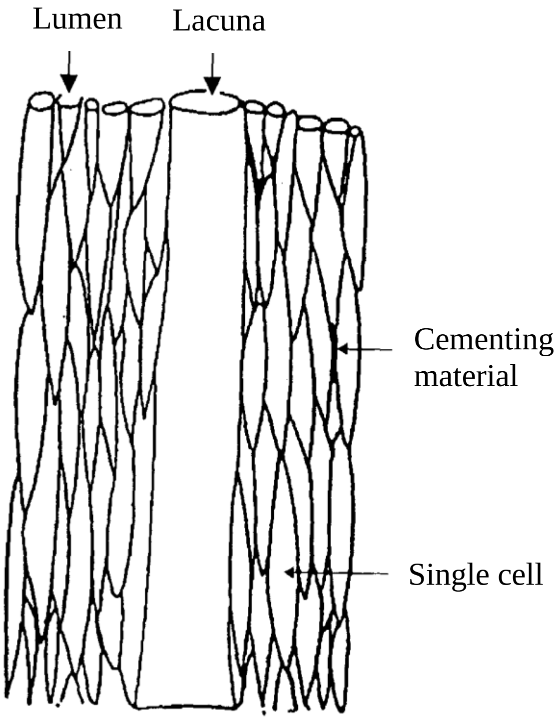


Fig. 2.6: Structure of lignocellulosic fiber showing arrangement of individual cells. (Mohanty et al., 2005)

Several methods for fiber modification such as grafting, coupling agents, pretreatments and alkalinization produce higher strength natural fibers for composites. Alkaline treatment using NaOH was chosen in this study due to several basic factors such as low cost treatment, easily available and also providing an effective fiber surface treatment. Studies done elsewhere positively shown an increase in mechanical properties. Results by Mishra et al. (2003) for sisal/glass and pineapple/glass reinforced polyester that used alkali chemical treatment showed highest mechanical strength. Investigation by Boynard and d'Almeida (2003) for luffa cylinderica/polyester composites shows that 5% concentration of NaOH provide best flexural properties. Edeerozey et al. (2007) using various concentration and found at 6% NaOH the average breaking strength is at the highest. Study done by Kostic et al. (2008) for hemp fibers proved that alkaline treatment yielded higher flexibility than unmodified fibers. According to Weyenberg et al. (2005), alkaline treatment affected the composites properties but reduces the natural fiber strength where the increase in total composites properties was due to an improved in interface adhesion and not improvement by fiber properties. Low NaOH concentration resulted in a reduced fiber diameter where the aspect ratio and the effective area in contact with the matrix increased (Weyenberg et al., 2005). Results by Weyenberg et al. (2005) also indicated that too high alkaline concentration leads to degradation of the crystal structure and only partial transformation into cellulose. According to Ray et al. (2001), crystallinity of the fibers increased only after 6 hours treatment where the modulus of the jute fibers increased by 12% at 4 hours of treatment and continuously increase by 68% and 79% when treated for 6 and 8 hours respectively. The tenacity at break point increased by nearly 46% after 6 and 8 hours treatment and the percent of breaking strain was reduced by 23% after 8 hours of treatment. Hence, according to Ray et al. (2001) composites prepared with natural fiber treated for 4 hours showed maximum mechanical improvements at all wt % fiber loadings whereby the improvement was maximum for composites prepared with 4 hours treated fibers at 35% fiber loadings. Fig. 2.7 shows that alkaline treatment provides higher fiber surface interaction by providing OH that allows for fiber surface chemical interaction.

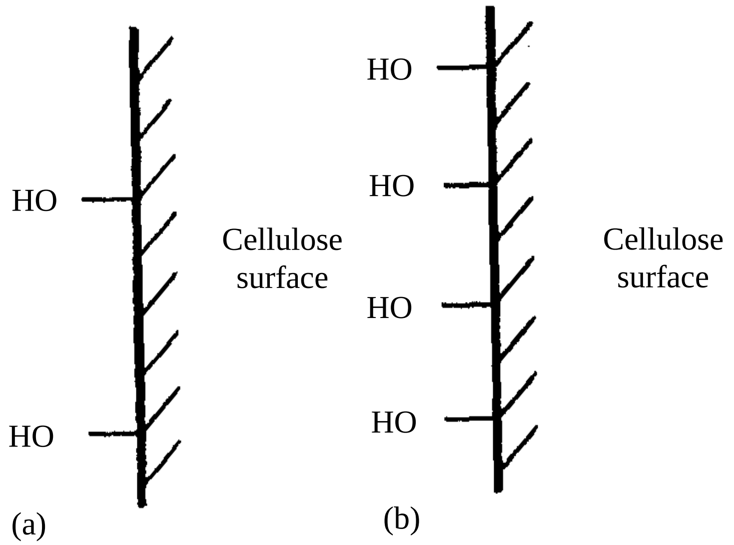


Fig. 2.7: Schematic representation of the natural fiber interphase of (a) non treated and (b) NaOH treated (Mohanty et al., 2005).

2.9 Bonding Mechanism for Natural Fiber

In general, the bonding mechanism involves is between the natural fiber surface and the resin. An example fiber surface treatment is shown in Fig. 2.8. Increased numbers of free -OH groups on the fiber surface increases the fiber-matrix bonding resulted in stronger bond at the interface (Ray et al., 2001). According to Mohanty et al. (2005), Vilay et al. (2008), Ray et al. (2002a) and Reddy and Yiqi (2005), the cellulose of natural fibers contains lignin and waxes and fiber surface treatment eliminate the waxy surfaces and remove the outer layers. However, according to Khan et al. (2005) the chemical modification of the fibers prevents hydrogen bonds from being formed thus better dispersion of fibers can be observed in the matrix. Untreated fiber shows rough and uneven surface while treated fibers shows smoother surface (Rong et al., 2001, Vilay et al., 2008, Sharifah and Martin, 2004, Edeerozey et al., 2007, Sgriccia et al., 2008 and Troedec, 2008). Hence, smoother surface does not promote surface interlocking mechanism between the fiber-matrix interfaces. However, the presence of waxy substances on the fiber surfaces resulted in in-effective fiber-matrix bonding and poor surface wettability (Vilay et al., 2008). According to Vilay et al. (2008), fiber surface treatment initiate the splitting of the fiber bundles to small fibers (fibrillation) to increase the effective surface area for fiber-resin interfacial enhancement. As such, treatment provide improvement in stress, stiffness and fiber rupture (Troedec, 2008 and Mishra et al., 2003).

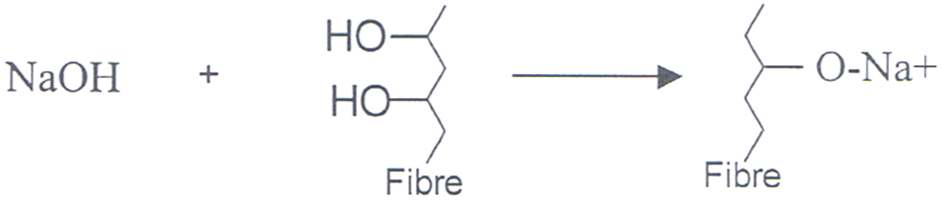


Fig. 2.8: Chemical modification (mercerization) to the natural fibres by treatments (Sreekala and Thomas, 2003)

2.10 Theoretical Modelling

The tensile modulus result is presented as a function of volume fraction of the fibers. In this study the model selected were Halphin–Tsai and Hersh model.

2.10.1 Semi-empirical Halphin-Tsai model

Calculation of Young's modulus for different type batches using semi empirical Halphin-Tsai model as per Equation 2.1 (Kalaprasad et al., 1997, Kaw 1997, Khalil and Rozman, 2004, Horrocks and Subhash, 2000 and Madsen et al., 2009);

$$E_{comp} = V_f E_f + V_m E_m \text{ (unidirectional/ continuous fibers)} \qquad (2.1)$$

where;

E_{comp} : Composites Young's modulus

V_f and V_m : Fiber and matrix volume fraction respectively

E_f and E_m : Fiber and matrix modulus respectively

According to Kaw (1997), the Halphin-Tsai equation for the longitudinal Young's modulus is similar with strength of material approach via rule of mixture. Hence, the rule of mixtures model is also commonly used to calculate the stiffness of unidirectional continuous fiber composites (Khalil and Rozman, 2004). According to Horrocks and Subhash (2000) and Madsen et al. (2009), the rule of mixture is used to determine the relationship between the fiber modulus and the composites modulus and to have a consistent in the modulus results.

Generally in order to calculate composites properties by the rule of mixture, the volume fraction and the weight fraction of the kenaf fiber, glass fiber and matrix are determined. The volume fraction and weight fraction is determined as per Equations 2.2, 2.3, 2.4 and 2.5 respectively (Kaw, 1997);

$$\text{Fiber volume fraction, } V_f = \frac{W_f/\rho_f}{W_c/\rho_c} \tag{2.2}$$

where;

W_f = Weight of fiber

W_c = Weight of composite

ρ_f = Density of fiber

ρ_c = Density of composite

$$\text{Fiber weight fraction } W_f = \frac{\text{Weight of fiber, } W_f}{\text{Weight of composite, } W_c} \tag{2.3}$$