ENHANCEMENT OF HYBRID FIBRE REINFORCED VINYL ESTER COMPOSITE USING NANOCOCONUT SHELL

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by

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LIST OF ABBREVIATIONS

Al	Aluminum
ASTM	American Society for Testing and Materials
Ca	Calcium
$CaCO^3$	Calcium carbonate
CNT	Carbon nanotube
CO^2	Carbon dioxide
EDX	Energy Dispersion of X-Ray
FT-IR	Fourier Transform Infrared Spectroscopy
GPa	Giga Pascal
MEKP	Methyl Ethyl Ketone Peroxide
MF	Mesocarp Fibre
Mg	Magnesium
MMT	Montmorillonite
MPa	Mega Pascal
MWCNTs	Multi-walled carbon nanotubes
PKE	Palm Kernel Expeller
PKS	Palm Kernel Shell
PS	Polystyrene
OPS	Oil Palm Shell
OPT	Oil Palm Trunk
SEM	Scacnning Electron Microsopy
SEM-EDX	Scanning Electron Microscopy With Energy Dispersion of X-Ray
Smax	Maximum stress level
Si	Silicon

SiCnp	Nano-sized silicon carbide particles
SiO^2	Silicon oxide
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
XRD	X-Ray Diffraction
CMCs	Ceramic Matrix Composite
MMCs	Metal Matrix Composite
PMCs	Polymer Matrix Composite

LIST OF SYMBOLS

%	Percentage
°C	Degree Celcius
cm	Centimeters
d	Thickness
g	Gram
J	Joule
kg	Kilogram
kN	KiloNewton
m	Meters
mg	Miligram
mm	Milimeter
nm	Nanometers
Nf	Fatigure Life
T50%	Degradation at 50% weight loss
Tf	Final Decomposition Temperature
Tg	Glass Transition Temperature
Ti	Initial Decompositon Temperature
Tmax	Decomposition Temperature
v	Volume
X	Magnification
Ѳ	Theta
ρ	Density

PENAMBAHBAIKAN KOMPOSIT VINIL ESTER DIPERKUAT GENTIAN HIBRID MENGGUNAKAN TEMPURUNG KELAPA NANO

ABSTRAK

Dalam kajian ini, gentian hibrid kenaf/sabut kelapa bertetulang vinil ester komposit dihasilkan dan diperkukuhkan dengan pengisi tempurung kelapa bersaiz nano. Tempurung kelapa telah dikisar dengan menggunakan tenaga kisaran bola yang pantas selama 30 jam supaya menjadi partikel tempurung kelapa bersaiz nano. Kemudian, pencirian nano pengisi untuk mendapatkan komposisi elemen, kumpulan berfungsi, dan morfologi permukaan telah dilakukan dengan menggunakan Spektroskopi Inframerah Transformasi Fourier (FT-IR) dan Pengimbas Mikroskopi Elektron dilengkapi dengan tenaga serakan X-ray analisis (SEM-EDX). Selain itu, Penghantar Elektron Mikroskopi (TEM), Analisis Belauan Sinar-X (XRD), dan Analisis Termogravimetri (TGA) telah digunakan untuk menghetahui saiz partikel, indeks penghabluran, dan sifat haba pengisi tempurung kelapa bersaiz nano. Manakala untuk kesan penambahan peratusan pengisi tempurung kelapa yang berbeza (0, 1, 3, dan 5 wt %) ke dalam gentian hibrid kenaf/sabut kelapa bertetulang vinil ester komposit telah dikaji. Komposit hibrid dipertingkat dengan pengisi nano telah disediakan dengan menggunakan teknik "handlay-up" dan dibiarkan dalam keadaan ditekan selama 24 jam pada suhu bilik supaya keras dengan sepenuhnya. Sifat-sifat fizikal, mekanikal, morfologi untuk komposit hibrid yang telah dipertingkat dengan pengisi nano telah dikaji. Imej-imej daripada SEM-EDX mendedahkan bahawa tempurung pengisi nano yang telah dihasilkan mempunyai bentuk yang tidak teratur dengan kehadiran karbon dan oksigen sebagai elemen utama komposisi. Penganalisis saiz partikel dan TEM menunjukkan bahawa pengisi

tempurung kelapa mempunyai saiz dalam kadar antara 55.63nm ke 92.35nm di mana ini menunjukkan sifat nano mereka. Peratus penghabluran pengisi tempurung kelapa adalah 26.84%. Berdasarkan keputusan yang diperoleh, peningkatan pengisi tempurung kelapa bersaiz nano ke dalam komposit hibrid telah meningkatkan ciri-ciri fizikal seperti ketumpatan,kandungan ruang kosong dan penyerapan air seiring dengan penambahan peratusan pengisi tempurung kelapa bersaiz nano. Sementara itu, bagi sifat-sifat mekanikal, tegangan, lenturan dan kekuatan impak meningkat apabila peratusan pengisi nano bertambah sehingga 3% dan kemudian berkurangan. Walaubagaimanapun, corak yang berbeza dipamerkan pada pemanjangan pada takat putus di mana penambahan peratusan pengisi nano mengurangkan pemnajangan pada takat putus. Kestabilan terma mempamerkan corak perubahan yang sama dengan sifat-sifat mekanikal. Untuk morfologi kesan hentaman, komposit hibrid dengan 3% pengisi nano menunjukkan ruang kosong yang minimum dan kehadiran gentian patah bukannya gentian tarik keluar. Ini menunjukkan bahawa tekanan daripada hentaman telah Berjaya diserap oleh gentian. Oleh itu, penambahan 3% pengisi nano tempurung dalam komposit hibrid dipercayai menjadi peratusan optimum yang boleh memberikan cirri-ciri komposit yang terbaik berbanding dengan peratusan penambahan pengisi nano tempurung yang lain.

ENHANCEMENT OF HYBRID FIBRE REINFORCED VINYL ESTER COMPOSITE USING NANOCOCONUT SHELL

ABSTRACT

In this research, hybrid kenaf/coconut fibres reinforced vinyl ester composites were produced and enhanced with nano filler made up from coconut shell. The coconut shells were grinded followed by high energy ball milling for 30 hours to become coconut shell nano particles. Characterization of coconut shell nano filler such as elemental composition, functional group and surface morphologies was done using Fourier Transform Infrared Spectroscopy (FT-IR) and Scanning Electron Microscopy equipped with Energy Dispersive X-ray Analysis (SEM with EDX) respectively. Besides, Transmission Electron microscope (TEM), X-ray Diffraction (XRD) and Thermogravimetric Analysis (TGA) were used to characterize particle size, crystallinity index and thermal properties of coconut shell nanofiller. Meanwhile, the effect of different coconut shell filler loading (0, 1, 3 and 5wt %) into hybrid kenaf/coconut fibre reinforced vinyl ester composite was studied. Hybrid composites enhanced with nano filler were prepared by using hand lay-up technique and left cured for 24 hours at room temperature. The physical, mechanical, morphology and thermal properties of hybrid composite enhanced with nano filler were studied. The SEM-EDX images revealed that coconut shell nano filler produced consisted and irregular shape with presence of carbon and oxygen as major elements composition. The particle size analyzer and TEM shows that coconut shell particle size ranged between 55.63 nm to 92.35 nm indicated nanometric nature. The percentage crystallinity of coconut shell nanofiller is 26.84%. It was observed that the incorporation of coconut shell nanofiller into hybrid composite increased physical properties such as density, void content and water absorption of composites

as filler loading increases. Meanwhile, for mechanical properties, tensile, flexural and impact strength increases as the filler loading increases up to 3% and then decrease. However, the opposite trends exhibited by elongation at break properties where the increment of filler loading reduced the elongation at break. The thermal stability exhibits the similar trends with mechanical properties. On morphological of impact fracture, hybrid composite with 3% filler loading showed minimum voids, presence of fibre fracture instead of fibre pull out. This indicated that the stress was successfully absorbed by the fibre. Therefore, the addition of 3% coconut shell nano filler in hybrid composite was believed to be an optimum percentage that can give remarkable properties compared to other percentages of nano filler loading.

CHAPTER 1 - INTRODUCTIONS

1.1 Overview

The increasing and growing in human population from day to day, living has led to the preservation of the environment that is not stable such as insufficient wood, fossil fuel, and increasing of environmental pollution. Based on the situation prevailing now, natural sources material or in the general waste and agriculture in particular has become a subject of interest in the present, either by industries or researcher. After many years of research, they found out that the use of these materials not only reduce various environmental issues but also contributing a major change in terms of costs, and technological point of view of science as well.

Malaysia is a country with a diversity of plant because of the suitable climate. Thus, there is huge number of biomass, forestry and agricultural waste accumulated every day. Natural plant fibres in Asean country has good quality in terms of strength, low density, at the same time have a cheap and affordable price. In addition, this natural plant fiber material is biodegradable and environmentally friendly (Saheb and Jog, 1999a). Due to these characteristics, natural fibers have attracted various industries because of its suitability for fabrication of composite applications. Among the natural fibers that are suitable and often used are hemp, jute, flax, kenaf, empty fruit bunch, bamboo, coconut fiber, and several others. Kenaf is a plant that is very important to be able to produce a strong fiber along with the best fiber of the world (Wambua et al., 2003).

Kenaf *(Hibiscus cannabinus L.)* is one of the fast-growing annual plants that can grow up to a height of about 3-4 meters in the period of 120-150 days, and is then ready for harvesting. Currently, there are many countries do research about this plant that potentially being used as one of the important natural fibre to replace the glass fibre (Wambua et al., 2003) . 284.100 MT of kenaf was produced all over the world in 2010. The main producer of kenaf in the world is India which can produce about 140.000 MT, followed by China that produced 75.000 MT and Thailand with 18.000 MT (IJSG, 2012). Kenaf also known as “the future crop” because of the excellent cellulose fibres sources (Tawakkal et al., 2012). Furthermore, based on previous study conducted, kenaf has been selected as one plant that has a strong fiber and can be the best reinforcement in composites (Tawakkal et al., 2012).

Coconut (*Cocos nucifera*) is one of Arecaceae species which is same as palm family. It is the fourth most major crop in Malaysia when comparing the acreage behind rubber, oil palm and rice (Sarki et al., 2011). Every part of the coconut palm can be used by human. Coconut shell and coconut coir fibre are several proportion of coconut which is lignocellulosic waste. The fraction of percentage for coconut coir fibre is 30-40% of coconut and coconut shell is 15-20% of coconut. The other is the percentages of endosperm and coconut water inside the coconut (La Mantia et al., 2005). Coconut shell is obtained from endocarp which surrounding the seed while coconut coir fibre is obtained from mesocarp or fibrous husk that protect the coconut shell. In a few asian country that has tropical climate such as Indonesia, India, Sri lanka, and Malaysia have choose coconut palm as one of their annual crop. Among these countries, Indonesia produced highest amount of coconut about 1800000 MT in year 2012 (FAO, 2012). Coconut shells are agricultural waste product that are frequently considered as a hardwood as the coconut shell are tougher than wood (Chun et al., 2012). Since before, coconut shells have low economic value and usually to dispose the waste are costly. But, many researchers had tried to make used the coconut shell and coconut fibres as they have excellent strength properties and have potential to be used as raw material for composite making, sound insulator, not influenced by dampness (Ali, 2011).

Composite is the combinations of materials that are varies in composition. Each material has their characteristic. When the material combined together, they can produce a new material that has both of the characteristic or a material that have the top quality compared to single material (Saheb and Jog, 1999a). Composite materials contain two or more different phases. Basic phases that usually used are matrix phase and dispersed phase. The matrix has several features that make it capable of sharing the load and capable of holding a dispersed phase, which is a ductile and less hard phase. While dispersed phase or reinforcing phase provide strength to the composite. Usually it has higher strength than matrix phase and it has discontinuous form. Most produced composite that being commercialized use polymer matrix or usually called a resin solution (dos Santos Rosa and Lenz, 2013). Now, there are many types of polymers which can be used according to the type of raw material and reinforcement according to the product to be produced (SUDHA et al., 2016).

1.2 Problem Statement

Composite materials that are made from biodegradable raw materials or natural materials and polymer materials have become public attention (Mohanty et al., 2002). Eco-composites made from natural ingredients that are safe for humans and environmentally friendly. They are very interesting because they are usually easier to handle, safe and work with as they are non-toxic materials. Technology in eco-composite materials has developed rapidly when demand from various industries also increased. Due to the technology in the manufacture of materials eco-composites have been developed and become one of the major factor that contribute to nation's economy (Cleveland, 2008).

Natural fibre is a substances that produced by animals and plant. It can be transformed into different forms, such as yarn or string, at the same time also can be woven, knitted, knotted into different shapes according to requirements. Based on this, natural fibre has potential to be use as good raw material for reinforcement for polymer composite due to its recyclability, low density and biodegradability (Chin and Yousif, 2009). Even though it has numerous advantages, there are certain drawbacks or disadvantages such as low in melting point, lack of interfacial adhesion, low modulus elasticity and undergo degradation process or aging towards humidity. Because of this drawback, natural fibre has becomes less attractive to be used as reinforcement of polymer composite.

In order to overcome this problem, nano particle has been identified as material that can enhance the natural fibre reinforced polymer composite properties. Although other concept of reinforcement has been studied to enhance the composite properties, using single nano particle of oil palm ash (OPA) (Khalil et al., 2012), oil palm shell

(OPS) (Dungani et al., 2013), coconut shell powder (Chun et al., 2012) and bamboo powder as filler in biocomposites (Shah et al., 2017), but the study that using coconut shell nano structured as fillers is still limited. Therefore, in this study, coconut shell nano size will be produced and used as filler to enhance the hybrid biocomposites.

1.3 Objectives of Study

The objectives of this research work are:

1. To characterize basic properties of nano-structured coconut shell nanofiller.
2. To evaluate hybrid kenaf/coir fibre reinforced vinyl ester composite enhanced with coconut shell nanofiller.
3. To study the properties and the effect of filler loading of coconut shell nanofiller on physical, mechanical, thermal and morphology properties of kenaf-coconut coir-kenaf fibre reinforced hybrid composites.

1.4 Organisation of Thesis

This thesis need been organized under 5 particular chapters, which are:

Chapter 1 : Focused on background, problem statement and objectives of present study.

Chapter 2 : Focused on literature review from present study regarding the composites classification, reinforcements crude materials, coconut shell, nanomaterial, polymer nanocomposites, and hybrid composites.

Chapter 3 : Clarify in regards to materials and the procedure to produce nano-structured coconut shell, characterization and also creation of hybrid composites.

Chapter 4 : Give the outcomes and discussion of characterization of nano-structured coconut shell and the effect of coconut shell nano-sturctured in hybrid kenaf/coconut coir fiber reinforced vinyl ester composites.

Chapter 5 : Abridges the overall conclusions and proposal for future examination of this study.

CHAPTER 2 - LITERATURE REVIEW

2.1 Composite

Composite can be defined as an engineering material consisting of two or more constituent materials with characteristics that differ significantly either in chemical, physical and mechanical that separated by a different interface. The combinations of different system impose a new system with the characteristics of the structure and function of the bulk is much different from the properties of individual constituents. The main phase of the composite contains characters that are recognized as the more ductile matrix, less hard, holding the secondary phase, and share load received. While the second phase is the discontinued phase that embedded in the matrix which resulting in higher strength or also known as reinforcement. Composites, is like miracle these materials become an important part of today materials as many advantages as low weight, low cost, corrosion resistance, high fatigue strength, and faster installation. It is widely used as a material in making the aircraft structure, electronic packaging for medical devices, parking space for construction of houses and even furniture (Shaw et al., 2010) ; (Malhotra et al., 2012).

2.1.1 Classification of Composite

Composite can be classified into several types. The classification of composite is depends on the raw material used to produce the composite and the type of the matrix used to bind the raw material. The classifications of composite based on the raw materials for the reinforcement are natural fibre and synthetic fibre. **Figure 2.1** illustrate the classification of the composite based on the type of matrix and type of raw materials used. Natural fibres are environmental friendly and biodegradable while petroleum-based synthetic fibers are not biodegradable and cause ecological, environmental and major global energy crisis.

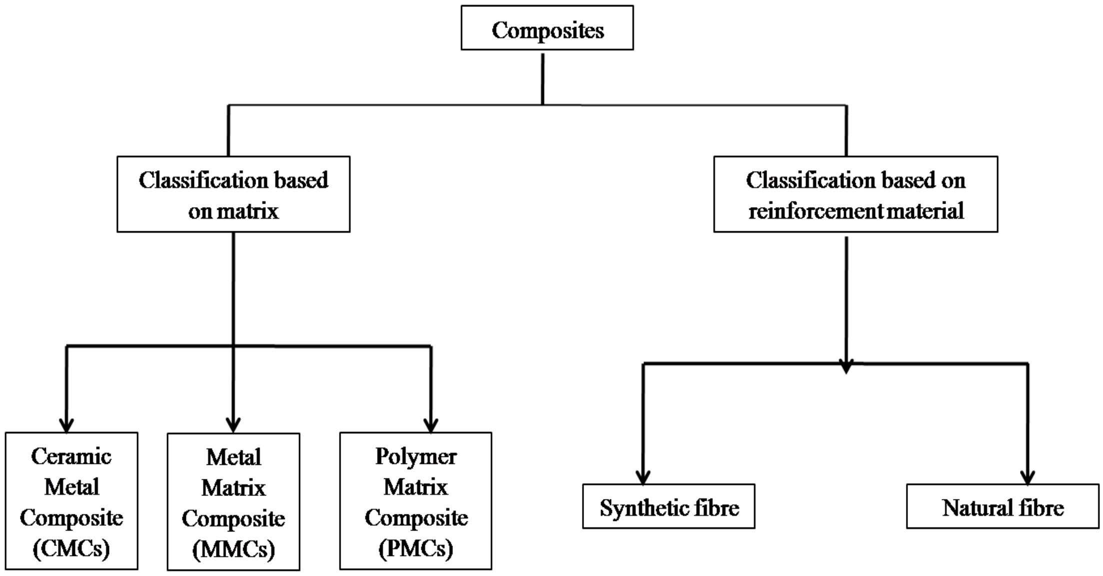

Figure 2.1 Classification of natural and synthetic fibers (Saba et al., 2015)

While, the classification of composite based on matrix are ceramics matrix composite (CMCs), metal matrix composite (MMCs), and polymer matrix composite (PMCs). The matrix also can be separated into two either biodegradable or non-biodegradable.

2.2 Natural fibres

Natural fibres are lignocellulosic fibres or can be called bio-fibres. Natural fiber is a source of bio-based materials that are the most abundant and renewable in nature (Majeed et al., 2013). Natural fibers especially based on their origin, whether comes from plants, animal, or mineral fibers. All plants fibres composed of cellulose, while the animal fibers consist of protein from animal hair, silk, and wool. Natural fibers are classified according to their origin or their botanical species. Complete classifications of the various natural fibers are shown in **Figure 2.2**.

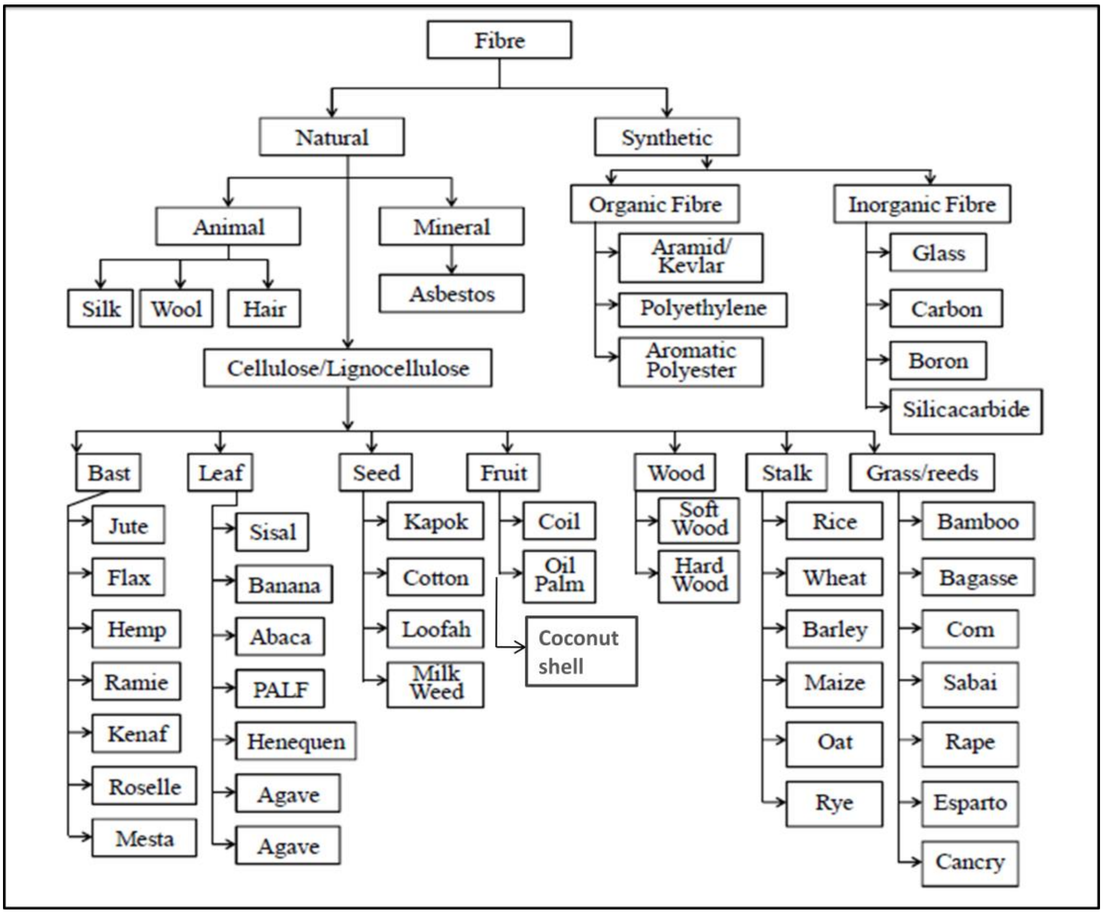

Figure 2.2 Classifications of materials composite (Malhotra et al., 2012)

Natural fibers were used as reinforcement or filling materials since 3000 years ago, incorporated with polymer materials. It was also used for composites as reinforcement because of their low cost, ease of separation, lower density, higher toughness, enhanced energy recovery, reduced dermal, respiratory irritation, and significant biodegradability (Mohanty et al., 2002).

The chemical composition of natural fibers depends on the type and nature of the fiber. The overall properties of fibers are influenced by the properties of each constituent. The changes in chemical composition from plant to plant, and in different parts of the same plant are different (Saheb and Jog, 1999a). The support for the entire major constituent of the cell wall is a sugar-based polymers (cellulose, hemicellulose), especially for dry basis. **Figure 2.3** shows the structures of cellulose and hemicelluloses. Cell structure and chemical composition of natural fibers rather complicated. Natural fibers themselves be regarded as natural composite consisting mainly of helically wound micro-fibrils of cellulose, lignin embedded in an amorphous matrix. Cellulose (a-cellulose), lignin, pectins, hemicellulose, and wax are the main component of natural fibers (Alhuthali et al., 2012).

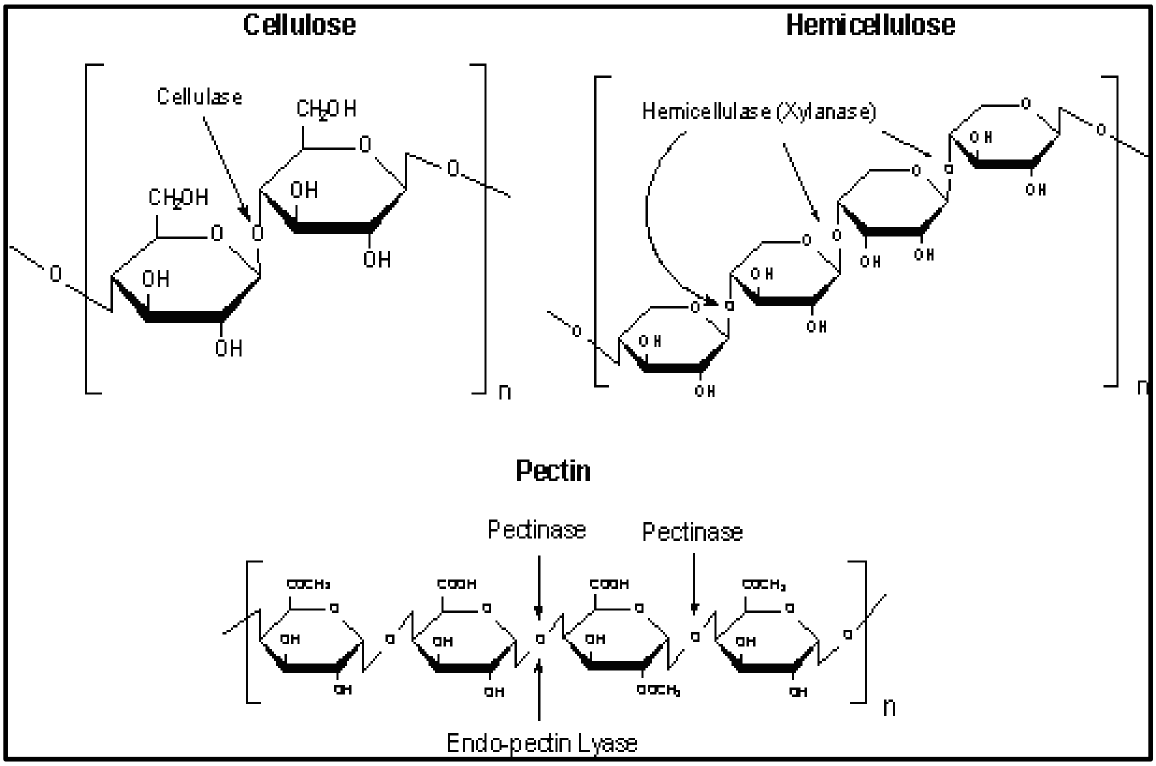

Figure 2.3 Cellulose, hemicellulose and pectin structures (http://www.bio.miami.edu)

Cellulose is a straight chain polymer of glucose molecule joined by ß (1-4) glycosidic bond. The multiple hydroxyl groups (OH) along a cellulose chain bond with the hydroxyl groups of other cellulose chains to form tight crystalline structures or known as microfibrils. Microfibrils have high tensile strength which provides resistance to being pulled apart, and are the major structural components of all plant cell walls (McCann et al., 2001). The hemicelluloses present in natural fibers are considered as compatibilizer between lignin and cellulose. Hemicellulose responsible for the thermal degradation of heat, moisture absorption, and biodegradable fibers as it shows less resistance but lignin thermally stable and is responsible for the UV degradation (Saheb and Jog, 1999a).

Phenylpropane is a lignin derivative and it is natural amorphous polymer that controls the transfer of fluids in plants (Majeed et al., 2013). Width and length of the fiber are the important parameter information used to compare a wide range of natural fibers. Therefore, the strength of the fibers can also be an important factor in choosing particular natural fibers for certain applications. Fiber morphology and anatomy of aquatic vegetation that is quite different from terrestrial fiber plants. The strength and stiffness of the fibers must be provided by hydrogen bonds and other linkage (Majeed et al., 2013).

Fiber variability, crystallinity, strength, dimensions, defects, and structure are the important factors that determine the properties of different natural fibers (Saheb and Jog, 1999a). The major disadvantage of natural fibers is their tendency of high water absorption and as the result, they become inequitable with nonpolar polymer matrices (Mohanty et al., 2001). Most of the resins are usually hydrophobic in nature and absorb little humidity. The void content and non-crystalline parts of the fibers are determined by the humidity of the fibers. The strength or mechanical properties of the natural fibers are affected by the hydrophilic nature of the fibers. The characteristic properties of natural fibers are affected by many factors, such as climatic conditions, maturity, harvesting and collection time, retting degree, decortications, disintegration (mechanical, steam explosion treatment), fiber modification, textile, and technical processes (Ibrahim et al., 2009).

The stiffness and strength of natural fibres are outstanding when used in the composites, they are easily recyclable, and moreover, bio-fibers will not easily be fractured when processing over sharp curvatures such as knife, saw etc., unlike brittle fibers, such as glass. In terms of strength perweight of the natural fibres also compete perfectly when compared with the conventional or traditional fibers, such as mica and glass that are usually used for composites. Natural-fiber-based packaging materials possess several benefits over synthetic packaging materials, such as the stiffness, recyclability and weight ratio (Oksman et al., 2003).

2.2.1 Natural (plant) fibre Composite

Natural fibre reinforced composite generally refers to natural fibres in any type or polymeric matrix either in thermoset or thermoplastic. It is also environmental friendly and biodegradable. These materials offer many of the same advantages and similar in strength and toughness as conventional composites together with their own unique advantages including low density, better compatibility matrix (Oksman et al., 2003). The performance of natural fiber polymer composites is influenced by several factors, such as microfibrillar fiber angle defects, structure, physical properties, chemical composition, cell dimensions, mechanical properties and interactions of the fiber with the polymer matrix. Therefore, to understand the properties of fiber reinforced composite material nature, it is important to identify the composition of mechanical properties, physical and chemical properties of natural fibers (Kalia et al., 2009). There are several matters to develop good performance of natural fibre reinforced composite which are the surface adhesion characteristics of the fibers, thermal stability of the fibers and the dispersion of the fibers in the case of thermoplastic composites (Hsiao, 2007)

However, the polarity of the natural fibre will cause incompatibility difficulties with many of the polymers. As the natural fibres have the hydrophilic or polar nature, it will reduces the interfaces bonding between polymer matrix and natural fibres. But nowadays, there a lot of chemical modifications or pretreatment of surface are made to improve the interfacial bonding between polymers and natural fibres (Azwa et al., 2013). Pre-treatment of natural fibers that are used to clean and uncontaminated the surface of the fiber, to modify the surface chemistry, reduce the tendency of the rate of moisture absorption, and to improve the external unevenness. Incorporation of natural fibers as a filler or reinforcement results in significant changes in the thermal stability of the polymer matrix. This composite manufacturing and processing involves the cooperation of the fibers and the matrix at a temperature high enough, thus, can lead to the destruction of bio-materials, which cause adverse effects on the properties of the last (Majeed et al., 2013). Almost all production techniques can be used to manufacture composites containing natural fibers such as hand lay-up and spraying technique, resin transfer molding, vacuum assisted resin transfer, casting injection molding and etc (Saheb and Jog, 1999b).

2.2.2 Polymer Composite

Polymer Matrix Composite (PMCs) consists of a variety of short or continuous fibers bonded together with a polymer matrix. The fibers will act as reinforcement in

PMC will provide high strength and stiffness to the composite. PMCs is created in order for the structure that are supported by the reinforcement to bear the mechanical loads subjected. While the function of the matrix, also known as resin is to bind the fibres together so that the load will be transferred between them. The most common matrixs used to produce PMCs are vinyl ester, polyester, epoxy and others. While the reinforcement materials that usually used are natural fibres, synthetic fibres and common ground minerals (Mkaddem et al., 2008); (Malhotra et al., 2012).

Various techniques have been developed to get the PMCs optimum properties of the mechanical and physical properties. The ratio of matrix and fibre that gives the best result is 60% matrix and 40% fibre. The ratio of matrix and fibre greatly affect the strength of PMC. PMC is very popular and widely used because of its low cost and it only uses simple fabrication methods to produce the PMCs. Different type of reinforcement of polymers by a variety of strong fibers allows the fabrication of PMCs, which has the following characteristics:

a) High specific strength and stiffness

b) High fracture resistance

c) Good abrasion resistance and impact resistance

d) Good corrosion resistance

e) Good fatigue resistance

f) Low cost

Despite have many advantages, there are still a few disadvantages which are PMCs have low thermal resistance when comparing with CMCs and MMCs. It also has high value of thermal expansion (Malhotra et al., 2012). Now, natural fiber-reinforced polymer composites have established a huge attraction and concern as innovative material in several applications in different fields. Although, natural fibre reinforced polymer composites have been commercialized, but their potential to be used in many industries has been limited. Therefore, a lot of studies in this area focus on improving the physical-mechanical properties and impact resistance of the composites (Saheb and Jog, 1999a);(Ku et al., 2011). Several ways to improve the mechanical properties of natural-fiber-based composites are to produce hybrid composites by combining several types of reinforcement/filler, enhanced with filler and do chemical treatment to the fibres before use as the reinforcement (Thwe and Liao, 2003);(Jacob et al., 2004).

2.3 Hyrid Composite

The word “hybrid” comes from Greek-Latin and can be seen in diverse scientific field. In polymer composite field, hybrid composites are the system when two types of fibres reinforced are incorporated together in a mixture of different matrices (blends) or two or more reinforcing materials present in a single matrix (Fu et al., 2002). The hybridization of different types of fibres for reinforcement into a single matrix gives improvement to the composite properties either in mechanical or physical strength. The properties of hybrid composite are the result of the combination between the individual component in which they have more beneficial balance between the natural advantages and disadvantages.

By hybridization of composite, what is lacking in one of material will be complemented by the other material or vice versa. Thus, hybrid composite is a good approach to produce a proper material that is low cost but has superior strength performance and the important thing is environmental friendly. This is important in order to meet the requirement of innovative applications (Thwe and Liao, 2003).

2.3.1 Hybrid Natural Fibres

Hybrid natural fibre refers to the combination of different type of natural fibres for the reinforcement of the composite. By applying this concept, the improvement of the composite can be achieved as what lacking in each type the fibre can be overcome from the advantages of the other fibre. The performance of hybrid composite basically depends on several criteria which are the fibre content, the orientation, extent of intermingling of fibres, length of individual fibres, fibre to matrix bonding and the arrangement of both fibres. Hybrid concept has become one of the factor to the incidents of a clear synergistic development in the performances of a composite that involve two or more types of fibre (Thomas and Pothan, 2009). A few factors should be considered when choosing the component for hybrid composite such as the purpose and the application. It must fulfill the requirement subjected on the composite produced to be used based on the purpose and the application (Mishra et al., 2003).

There are several categories of hybrid composite such as interplay, sandwich hybrids, interply and intimately mixed hybrid. Interplay is an arrangement of the two or more element types of fibre that are combined in a regular form or by random technique. Meanwhile, sandwich hybrid or can be referred as core-shell is a material which being stacked together between two layers of another. Interply or laminated hybrid composite is where alternate layers of two or more materials are arranged in a regular technique. The last one is the intimately mixed hybrids can be defined as the constituent fibre randomly mix as possible thus no over concentration of any one types is present in the material. Other types such as those reinforced with ribs, pultruded wires, thin veils of fibre or combinations of the above (M Muhammad et al., 2013).

Hybrid composites were developed by various researchers (Thomas and Pothan, 2009; Majeed et al., 2009; Mohaiyiddin et al., 2013) by combining natural fibers/natural fiber and natural fibers/synthetic fibers with epoxy, polyester, phenolic, poly vinyl ester, poly urethane resin and many others. The environmental awareness attracted researchers to develop new composites with addition of more than one reinforcement from natural resources, such as natural fiber/natural fiber or natural fiber/nanofiller from organic sources as an alternative to replace the synthetic fibers. Hybridization involving the combination of nanofiller and natural fiber in the matrix results reduction of water absorption properties and increased in mechanical properties. Several research works depicts all these facts. The mechanical and thermal properties of rice husk flour with high density polyethylene composites get improved by addition of small amount of nanoclay (Kord, 2011; Majeed et al., 2013). While Sarlin and Immonen (2013) studied the dynamic properties of polypropylene composite with hybrid nanofiller.

Mechanical and tribological performance of the hybrid date palm fiber and epoxy composites get enhanced by addition of graphite filler but high content of the graphite deteriorates the mechanical properties (Shalwan and Yousif, 2014). Natural fiber/nanofiller-based hybrid composites can be utilized in building and construction materials, transportation specifically in automobiles, railway coaches, aerospace packaging, consumer products and also could be possible to produce acoustic insulator and extremely thermally stable materials (Saba et al., 2015).

2.4 Matrix

Matrix is a material consists of one or more components in its composition Matrix serves as supportive system that protects the composites from the incursion of external agents as it binds the reinforcement together, as it helps in stress and load transfer within the composite structure (Thakur et al., 2010). Matrix is an important ingredient to obtain best properties of composite. Natural fibre reinforced composite material, matrix act as a binder to hold the fibre together. Besides, the matrix has the ability to transfer the load applied to the fibre reinforced and also defend these fibres from harmful environmental effects (Cleveland, 2008). Basically, the matrix can be divided into two categories, which are thermosets and thermoplastics. Thermoplastic resins will soften when heated and harden when cooled while thermosetting is a resin that will cure either heated or by using a catalyst. Solid thermoset resin cannot be changed in original form once the resin cured (Osman et al., 2012). The final composite product will determine what type of resin should be used to produce the composite and also depend on the application of the composite (Saheb and Jog, 1999b).

2.4.1 Thermosetting Resin

Thermoset polymer consists of amorphous structure which molecules are connected by covalent bond that form strong network structure. Thermosetting materials are formed from a chemical reaction where the resin and the catalyst are mixed and then undergo a non-reversible reaction to form a hard and infusibble product (Cleveland, 2008). Once the curing process or polymerization reaction occurs, it cannot be undone to liquid form even been heated, but instead permanently deteriorate (Daniel et al., 1994). The type of matrix that frequently used in composites field are unsaturated polyester, epoxy and vinyl ester resin (Saheb and Jog, 1999a).

2.4.1 (a) Vinyl Ester Resin

Early 1960s, vinyl ester resin was introduced and commercialized to the industries. Vinyl ester resin is one of the thermoseting polymers that still being used till now. Vinyl Ester resin is produced from the esterification of unsaturated monocarboxylic acid with an epoxy resin (Abadie et al., 2002). The end product of the reaction obtained was dissolved in a reactive solvent, for the example is styrene, in the range of 35–45% content by weight (Mohamed et al., 2014). In many industrial products, vinyl ester resin consists of 40-50 wt. % styrenes. It is common to dilute the vinyl ester oligomers with styrene that has the properties of low molecular to reduce the viscosity of the mixture at room temperature and the resulting solution that has a viscosity in the range of 200-2000 cps (Abadie et al., 2002)

Vinyl ester resins combine the best features of epoxy and unsaturated polyester. The mechanical properties of vinyl ester resin similar to epoxy resin and it also can easily be handled at room temperature. The chemical resistance is also better than polyester, particularly in hydrolytic stability, and at once it gives greater control and better on the cure rate and the reaction of epoxy resin (Ku, 2003). Vinyl ester resins show many interesting properties, such as the ability to cure at room temperature, has a low viscosity, low price and have the same characteristics with the other outstanding ordinary thermosetting matrix (Stone et al., 2000). The low viscosity properties of this resin make this resin has high wettability towards the reinforcement materials (Abadie et al., 2002).

However, there are certain disadvantages regarding this resin such as it requires post cure process to give enough time for the resin to fully cure and produce high properties of material. It also uses high styrene content as its monomer, and high cure shrinkage. The surface quality of vinyl ester resin is not very good compared to polyester resin. Smooth surface is not easy to achieve when using vinyl ester as the double bonded nature of the resin that provide toughness will create shrinkage and causes the surface quality reduced (Mohamed et al., 2014).

For thermosetting categories, vinyl ester has built up a good reputation and became one of the most important resin by the industries beside epoxy and polyester resin. This is because vinyl ester has outstanding properties such as excellent resistance towards the different chemical environment and also suitable to fabricate many reinforced structures such as tanks, scrubbers, ducts, pipes and so on. Furthermore, vinyl ester resin is also being used in composite for infrastructures and transportation or automotives. These applications include certain part of automobiles regardless of the interior part or the exterior part. Vinyl ester is also being used in structural laminates, reinforcement for bridge, fascia for building, electrical applications, coatings technology, even in military and aerospace applications (Alhuthali et al., 2012).

There are plenty of current research done using natural fibres as reinforcement towards vinyl ester polymer composites has been studies, such as bamboo, kenaf (Fairuz et al., 2015), flax (Amiri et al., 2015), sisal (Jacob et al., 2004), banana (Ghosh et al., 2014), jute (Praharaj et al., 2015), coir (Khalil et al., 2008), oil palm