DEVELOPMENT AND CHARACTERIZATION OF OIL PALM EMPTY FRUIT BUNCH/JUTE FIBRES REINFORCED EPOXY HYBRID COMPOSITES

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By

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LIST OF ABBREVIATIONS

ATL	Automatic tape laying
ANOVA	One-way analysis of variance
ASTM	American Society for Testing and Materials
BMC	Bulk molding compound
BG	Between-group component
CO_2	Carbon dioxide
DICY	Dicyandiamide
Df	Degree of freedom
DGEBA	Diglycidyl ether of bisphenol-A
DMA	Dynamic Mechanical Analysis
EFB	Empty Fruit Bunches
EHA	2-Ethyl hydroxy acrylate
ELV	End of life vehicle
FRP	Fibre Reinforced Polymer
FT-IR	Fourier Transform Infrared
FDT	Final decomposition temperature
GPa	Giga Pascal
HEMA	2-Hydroxyethyl methacrylate
HEA	2-Hydroxy Ethyl acrylate
IDT	Initial decomposition temperature
kPa	Kilo Pascal
LCA	Life cycle assessment
MPa	Mega Pascal

MARDI	Malaysian Agricultural Research and Development Institute
MPOB	Malaysian Palm Oil Board
MDF	Medium Density Fibre Board
MPS	3-methacryloxypropyl tri-methoxy silane
MS	Mean square
OH	Alcohol group
PALF	Pine Apple leaf Fibres
PU	Poly urethane
PF	Phenol formaldehyde
PVC	Poly Vinyl Chloride
Phr	Parts by weight
RIM	Reaction injection molding
RTM	Resin transfer molding
SEM	Scanning Electron Microscope
SMC	Sheet molding compound
SLS	Sodium lauryl sulphate
SRIM	Structural reaction injection molding
SS	Sum of square
TGA	Thermogravimetric Analysis
VMS	Vinyl tri-methoxy silane
VE	Vinyl ester
WPG	Weight percent gain
WG	Within-group component

LIST OF SYMBOLS

b	width
C	Co-efficient
cc	Cubic centimetre
cm	Centimeter
C=O	Carbonyl group
d	Thickness
E’	Storage modulus
E”	Loss modulus
E''_{max}	Maximum storage modulus
E'_g	Storage modulus value in the glassy region
E'_r	Storage modulus value in the rubbery region
g	Gram
Hz	Hertz
J	Joule
J_w	Woven jute
Kg	Kilogram
L	Span length
m	Mass
mm	Millimeter
N	Newton
T_g	Glass transition temperature
UV	Ultra violet
V	Volume

V_f Volume fraction

W_f Weight fraction

μm Micrometer

ρ_f Fibre density

ρ_c Composite density

δ delta

LIST OF PUBLICATIONS & CONFERENCE PROCEEDINGS

PEMBANGUNAN DAN KARAKTERISASI KOMPOSIT HIBRID EPOKSI GENTIAN TANDAN KOSONG KELAPA SAWIT/ JUT DIPERKUAT

ABSTRAK

Kajian ini berkaitan dengan penghasilan komposit hibrid dan komposit hibrid teranyam menggunakan kaedah ‘hand lay-up’. Dalam kombinasi kajian yang unik ini, gentian tandan kosong kelapa sawit (TKKS) dan jut mempunyai perbezaan penting dalam sifat mekanikal dan fizikal telah digunakan sebagai penguat dalam matriks epoksi. Kesan pemuatan gentian jut terhadap sifat mekanikal, fizikal, kimia dan terma komposit TKKS telah dikaji. Pemerhatian penggabungan gentian jut dalam komposit TKKS telah meningkatkan sifat tensil dan lenturan tetapi menurunkan sifat impak. Penghibridan komposit TKKS dengan gentian jut telah mengurangkan kandungan rongga dan menigkatkan kestabilan dimensi. Pengaruh urutan terkumpul pada mekanikal, fizikal, ketahanan kimia dan sifat terma komposit hibrid dinilai dan dibandingkan dengan komposit TKKS, jut dan epoksi. Peningkatan yang signifikan telah diperhatikan pada sifat tensil dan lenturan komposit hibrid berbanding dengan komposit TKKS, sedangkan kekuatan impak komposit TKKS lebih tinggi daripada komposit hibrid. Pemerhatian ini menandakan bahawa pengurangan kandungan rongga komposit hibrid adalah dalam pola lapisan yang berbeza berbanding dengan komposit komposit TKKS. Penghibridan komposit TKKS dengan gentian jut telah meningkatkan kestabilan dimensi dan ketumpatan komposit TKKS dan komposit jut dimana komposit jut mempunyai ketumpatan yang lebih tinggi berbanding dengan semua komposit lain. Komposit hibrid teranyam telah diperkuatkan dengan gentian jut teranyam dan sifat mekanikal, fizikal, ketahanan kimia dan terma komposit hibrid teranyam telah diselidiki berdasarkan berat pecahan dan pola lapisan dari gentian jut. Komposit hibrid teranyam telah menunjukkan peningkatan sifat tensil dan lenturan, sedangkan komposit TKKS menunjukkan peningkatan bagi sifat impak. Sifat tensil dan lenturan komposit hibrid memberikan pembaharuan yang jelas berbanding dengan komposit hibrid yang diperkuat gentian jut tidak teranyam. Komposit hibrid teranyam yang mempunyai kandungan rongga yang tinggi menghasilkan kestabilan dimensi yang lebih rendah berbanding dengan komposit hibrid yang diperkuat gentian jut tidak teranyam. Pengubahsuaian kimia dari gentian jut dan TTKS telah meningkatkan ikatan permukaan gentian/matriks dan menghasilkan sifat mekanikal dan fizikal yang dipertingkatkan. Hal ini ditemui dari ujian ketahanan kimia dimana semua komposit tahan terhadap pelbagai bahan kimia. Analisis statistik bagi komposit yang dilakukan dengan ANOVA satu cara menunjukkan perbezaan yang signifikan antara hasil-hasil yang diperolehi. Pemuatan gentian jut, gentian jut teranyam dan pengubahsuaian kimia mempengaruhi sifat mekanikal dinamik komposit hibrid. Analisis Cole-cole dilakukan untuk memahami perilaku fasa komposit hibrid. Keputusan analisis terma gravimetri menunjukkan peningkatan kestabilan terma komposit TKKS dengan penggabungan dari gentian jut,gentian jut teranyam dan gentian terubahsuai kimia. Keputusan keseluruhan menunjukkan bahawa penghibridan TKKS dengan jut dan gentian jut teranyam telah meningkatkan sifat mekanikal dinamik dan terma.

DEVELOPMENT AND CHARACTERIZATION OF OIL PALM EMPTY FRUIT BUNCH/JUTE FIBRES REINFORCED EPOXY HYBRID COMPOSITES

ABSTRACT

Present work deals with the designing of hybrid and woven hybrid composites by hand lay-up method. In this work unique combination of oil palm empty fruit bunch (EFB), and jute fibres having notable differences in mechanical and physical properties have been used as reinforcement in epoxy matrix. The effect of jute fibre loading on the mechanical, physical, chemical and thermal properties of EFB composite was studied. It was observed that incorporation of jute fibre into EFB composite enhanced tensile and flexural properties but reduced impact properties. The hybridization of the EFB composite with jute fibres reduced the void content, and showed improvement in dimensional stability. The effect of stacking sequence on mechanical, physical, chemical resistant, and thermal properties of hybrid composites were evaluated and compared with the epoxy, EFB, and jute composites. A significant improvement was observed in tensile and flexural properties of hybrid composites as compared to EFB composite, whereas the impact strength of EFB composite was found to be higher than those of hybrid composites. It was observed that marked reduction in void content of hybrid composites in different layering pattern as compared to EFB composite. Hybridization of oil palm EFB composites with jute fibres improved the dimensional stability and density of jute composite has higher density as compared to all other composites. Woven hybrid composites were reinforced with plain weave jute fibres and mechanical, physical, chemical resistant, and thermal properties of the woven hybrid composites were investigated with respect to weight fraction and layering patterns of jute fibres. Woven hybrid composites show increase in tensile and flexural properties, while oil palm EFB composite reveal enhanced impact properties. Tensile and flexural properties of hybrid composites exhibited obvious improvement as compared with the non woven jute fibres reinforced hybrid composites. The high void content of woven hybrid composites resulted in lower dimensional stability compared to non woven jute based hybrid composites. Chemical modification of jute and EFB fibres increased fibre/matrix interfacial bonding and it results in enhanced mechanical and physical properties of hybrid composites. It was found from the chemical resistance test that EFB, jute, woven jute, and hybrid composites, resistant to various chemicals. Statistical analysis of composites done by ANOVA-one way showed significant differences between the results obtained. Jute fibre loading, layering pattern, woven jute fibres, and chemical modification affect the dynamic mechanical properties of hybrid composites. Cole-Cole analysis was made to understand the phase behaviour of the hybrid composites. Thermo gravimetric analysis indicated an increased in thermal stability of EFB composite with the incorporation of jute, woven jute and chemically modified fibres. The overall results showed that hybridization of oil palm EFB with jute, woven jute and chemically modified fibres enhanced the dynamic mechanical and thermal properties.

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background

A composite is a complex solid material, made by combining two or more dissimilar materials in such a way that the resulting material is endowed with some superior and improved properties. Owing to these superior properties, polymer composites find various applications in our daily life. Composites are light weight, high strength to weight ratio and stiffness properties have come a long way in replacing the conventional materials such as metals and wood. Composites materials are attractive because they combine material properties not found in nature. Such materials often results in light weight structures having high stiffness and tailored properties for specific applications, there by saving weight and reducing energy needs. Due to increased pressure from environmental activists, preservation of natural resources and attended stringency of laws passed by developing countries leads to invention and development of natural fibre based composites with focus on renewable raw materials (Anandjiwala and Blouw, 2007, Wittig, 1994, Satyanarayana et al., 2009).

In this global context, the composites market is expected to grow on average at 4% p.a. from 60 Billion Euro (8.6 Metric tonnes) in 2008 to 80-85 Billion Euro in 2013 (10 Metric tonnes) (JEC Press releases, 2009). The U.S. market for composites increased from 2.7 billion pounds in 2006 to an estimated 2.8 billion pounds in 2007. It should reach over 3.3 billion by 2012, a compound annual growth rate of 3.3 % (Business Communication Company, 2007). The automotive market sector is not the only area that has experienced an increase in natural-fibre usage. The insertion of natural fibers in the industrial, building, and commercial market sectors has experienced a growth rate of 13% compounded over the last 10 years to an annual use of approximately 275 million kilograms (Report, 2004). The Fibre-reinforced composites market is now a multibillion-dollar business (Material and Thoughts, 2002).

Natural fibres from renewable natural resources offer the potential to act as a biodegradable reinforcing materials alternative for the use of synthetic fibres. Natural fibres offer various advantages such as low density, low cost, biodegradability, acceptable specific properties, better thermal and insulating properties, low energy consumption during processing etc. (Rout et al., 2001, Rana et al., 2003, Joshi et al., 2004). Natural fibres are neutral with respect to the emission of CO_2, and this put natural fibres as materials in context with the Kyoto protocol (Mohanty et al., 2002). The leading driver for substituting natural fibres for glass is that they can be grown with lower cost than glass (Satyanarayana et al., 2009).

Extensive studies have been done on natural fibres reinforced composites such as sisal (Dwivedi et al., 2010, Srisuwan and Chumsamrong, 2010), jute (Alves et al., 2010, Alamgir Kabir et al., 2010, Mir et al., 2010), flax (Cherif et al., 2010, Di Bella et al., 2010), hemp (Islam et al., 2009, Islam et al., 2011, Longkullabutra et al., 2010, Santulli and Caruso, 2009), kenaf (Abu Bakar et al., 2010, Xue et al., 2009, Rozman et al., 2011, Rozman et al., 2010a), banana (Maleque et al., 2007, Sapuan et al., 2007, Annie Paul et al., 2008) and oil palm EFB (Abdul Khalil, 2010d, Hassan et al., 2010, Bakar et al., 2010, Abdul Khalil et al., 2008a, Rozman et al., 2010b), pineapple (Liu et al., 2005, Lopattananon et al., 2008), have shown that natural fibres have the potential to act as effective reinforcement in thermoset and thermoplastic matrix.

Hybrid composites reinforced with oil palm EFB/glass fibres (Abdul Khalil et al., 2009, Abdul Khalil et al., 2007a, Abu Bakar et al., 2005, Karina et al., 2008, Wong et al., 2010, Sreekala et al., 2002, Sreekala et al., 2005, Rozman et al., 2001, Anuar et al., 2006) and jute/glass fibres (Esfandiari, 2007, Koradiya et al., 2010, Srivastav et al., 2007, De Rosa et al., 2009b, De Rosa et al., 2009a, Akil et al., 2010, De Carvalho et al., 2010, Ahmed and Vijayarangan, 2008) already demonstrate good mechanical and physical properties compared to unhybridized composites. Polymer composites with hybrid reinforcement solely constituted of natural fibres are less common, but these are also potentially useful materials with respect to environmental concerns (Idicula et al., 2010, Athijayamani et al., 2009, Khan et al., 2009, Saw and Datta, 2009, De Carvalho et al., 2007, Thiruchitrambalam et al., 2009).

1.2 Problem statement

The interest in natural-fibre reinforced hybrid composites is growing rapidly owing to their great performance, significant processing advantages, bio-degradability, low cost and low relative density. Hybrid composites have the potential advantage of light material, cheap raw material from natural origin, and thermal recycling or the ecological advantages of using resources which are renewable and sustainable. The behaviour of hybrid composites is a weighed sum of the individual components in which there is more favourable balance between the inherent advantages and disadvantages. At present, by-products of oil palm mills are not efficiently utilized, and the explosive expansion of oil palm plantation has generated enormous amounts of vegetable waste, creating problems in replanting operations and tremendous environmental concerns. The primary advantages of using oil palm EFB fibres in hybrid composites are its low densities, non abrasiveness and biodegradability. Jute is the second most important vegetable fiber after cotton, in terms of usage, global consumption, production, and availability. It has high tensile strength, insulating and antistatic properties, as well as having low thermal conductivity and a moderate moisture regain. Epoxy resin has an attractive combination of stiffness, strength, high heat distortion temperature, good thermal & environmental stability and high creep resistance.

Fibres having higher cellulose content found to be stronger than those with low cellulose content as long as their micro-fibril angle is small (Mwaikambo and Ansell, 2006). The cellulose content of jute fibres is higher than oil palm EFB fibres but the micro-fibril angle of jute fibre (8^0) is much lower than oil palm EFB fibres (46^0). Hence, inherent tensile properties of jute fibres are higher than oil palm EFB fibres. Since micro-fibril angle of oil palm EFB is high, the impact strength of oil palm EFB fibre will be higher. Models indicate that fibre stiffness is influenced by the micro-fibril angle of the crystalline fibrils as well as the concentration of the non-cellulosic substances (Bledzki and Gassan, 1999). A Jute fibre has small lumens (Cichocki Jr and Thomason, 2002, Henriksson et al., 1997). The lumen size of jute fibre is lower than oil palm EFB fibres (Munawar et al., 2010). Diameter of jute fibres is lower than oil palm EFB fibre (Hassan et al., 2010). As surface area of jute fibre in unit area of composite is higher, the stress transfer is increased in jute fibre reinforced polymer composite compared to oil palm EFB fibre reinforced composites.

This research work tries to explore the potential utilization of jute fibres as composite reinforcement with combination of locally available oil palm EFB fibres reinforcement in epoxy matrix. In the present study, natural fibre based hybrid composites with oil palm EFB fibres and jute fibres keeping total fibre loading of

40% by weight were prepared by hand lay-up method. Previous study indicated that 40% fibre loading give optimum tensile strength and modulus, flexural strength and modulus, and better fibre/matrix bonding (Idicula et al., 2005c). Fabrication of bi-layered hybrid composites indicated that hybridization with 20% jute fibre gives rise to sufficient modulus to EFB composite. In this research, further study limited to trilayer hybrid composites by keeping weight ratio of oil palm EFB and jute of 4:1 because hybridization of EFB composite with 20% jute fibres enhanced utilization of locally available EFB fibre in advance and high performance applications. The mechanical, physical, chemical resistance, and thermal properties of oil palm EFB/jute hybrid composites with respect to fibre weight fraction, layering pattern, woven, and chemically modified fibres were studied. The properties obtained in different parameter were compared to analyze the effectiveness of hybrid composites.

Challenges still exist in the development of more suitable cost-effective fabrication techniques as well as composites having superior mechanical properties using natural fibres as reinforcement. Nevertheless, the progress so far obtained in this field has allowed the application of natural-fibre polymer composites in many sectors such as in consumer items and, more importantly, in the automotive industry.

1.3 Scope of the Present Work

The aim of present work is to fabricate and characterize the feasibility of using oil palm EFB and jute fibre as reinforcement in epoxy matrix. Present study deals with the development of chopped strand fibre hybrid composites as well as woven hybrid composites. Several researchers have already worked on other natural fibres such as sisal, banana, hemp, flax, kenaf, silk etc. The literature survey on hybrid composites based on epoxy resins indicated that until now, no work has been reported on epoxy based hybrid composites of oil palm EFB and jute fibres. Presently, oil palm EFB fibres and jute fibres are underutilized. The EFB fibers which is easily available in Malaysia and can thus be utilized as a reinforcing material along with jute fibers within epoxy resin, so that the concerns about the application problems of this by-product can be solved.

The advantage offered by oil palm EFB fibres and jute fibres are that they are cheap, renewable, biodegradable, easy to handle and dispose and they have good strength to weight ratio, which has an eminent importance for composite applications. This new family of composite materials frequently exhibits remarkable improvements of mechanical, physical, and material properties compared with EFB and jute composites. The automotive and aerospace sectors have been identified as future industries for natural fiber hybrid composites. Many automotive and aero-plane components are already produced in natural composites, mainly based on epoxy or polyester and natural fibers.

1.4 Objectives of the Study

The objectives of this present research work are:

1. To study the effect of jute fibre loading on the mechanical, physical, chemical resistance, and thermal properties of oil palm EFB fibre/jute fibre hybrid polymer composites.
2. Assessing the effect of stacking sequence on the physical, mechanical, chemical resistance and thermal properties of oil palm EFB/jute fibre hybrid composites.

3. Evaluation of the effects of fibre architecture (woven fibre) on the physical, mechanical, chemical resistance, and thermal properties of oil palm EFB fibre/jute fibre hybrid composites.
4. Study the effect of fibre treatment on the physical, mechanical, chemical resistance, and thermal properties of oil palm EFB fibre/jute fibre hybrid composites.

1.5 Organization of Thesis

This thesis has been structured into 5 respective chapters.

Chapter 1-Introduction, focused on introducing and background, major challenges/gaps, scope of study and objectives of study.

Chapter 2- Focussed on literature review of various aspects of natural fibres, matrix, oil palm EFB and jute fibres and its composites. It also covered detail scientific information about hybrid composites.

Chapter 3-Explains about materials and methodology of development and characterization of hybrid composites.

Chapter 4-Deals with results and discussion of mechanical, physical, chemical resistance, and thermal properties of hybrid composites and its output related with previous published works.

Chapter 5-Summarizes the overall conclusions and recommendation for future research proposals of this study.

CHAPTER-2

LITERATURE REVIEW

2.1 Composites

A composite material is a heterogeneous combination of two or more different constituents (reinforcing elements, fillers and binders) differing in form or composition on a macro-scale and micro-scale. The combination results in a material that maximizes specific performance properties. The constituents do not dissolve or merge completely and therefore, normally exhibit an interface between one another(Anandjiwala and Blouw, 2007).

2.2 Classification of Composites

Composite materials are classified on the basis of matrix material (metal, ceramic, and polymer) and material structure (Kopeliovich, 2010) illustrated in Figure 2.1.

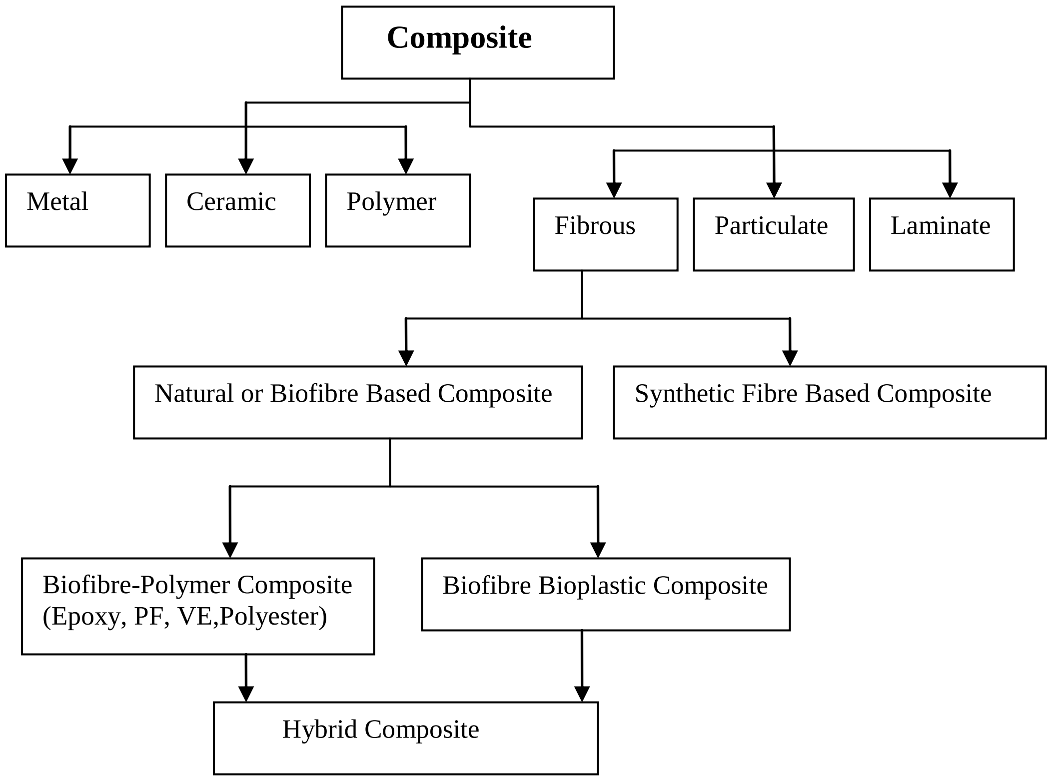

Figure 2.1 Schematic representation of classification of composites

2.3 Matrix

Matrix is usually plastics material which used as binder and holds the reinforcing materials in its place. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it (Kopeliovich, 2010). When composite is subjected to applied load, the matrix deforms and transfers the external load uniformly to the fibres (Astrom, 1983, Jaffar, 1998).

Matrix generally classified into two broad categories, thermoplastics and thermosets. The selection criteria of the matrices depend solely on the composite end use requirements.

2.3.1 Thermoset-based matrix

Thermoset resins are usually liquids in their initial form and after addition of harder it converted to a hard rigid solid by chemical cross-linking through a curing process. Cross-linking involves the application of heat or occurs at room temperature. Once cured, a tightly bound three dimensional network structure is formed in the resin and hence, the resin cannot be melted, reshaped and reprocessed by heating (Hull and Clyne, 1996). Thermoset resins are brittle at room temperature and have low fracture toughness. Due to three dimensional cross linked structure, thermoset resins have good thermal stability, chemical resistance, dimensional stability, and also high creep properties (Schwartz, 1992). Common types of thermoset resin used for manufacturing composite materials are epoxies, polyesters, vinyl esters and phenolics. Typical properties of four thermoset resins are tabulated in Table 2.1.

To achieve reinforcing effects in composites it is necessary to have good adhesion between the fibres and resins. Epoxy and phenolic thermosetting resins are known to be able to form covalent cross-links with plant cell walls via -OH groups

Table 2.1 A comparative study of the properties of Epoxy, Polyester, Vinyl ester, and Phenolic Resin (Rout, 2005).

Properties	**Polyester Resin**	**Epoxy Resin**	**Vinyl ester Resin**	**Phenolic Resin**
Density(g/cc)	1.2-1.5	1.1-1.4	1.2-1.4	1.3
Tensile Strength (MPa)	40-90	35-100	69-83	10
Young's modulus (GPa)	2-4.5	3-6	3.1-3.8	0.375
Elongation at break (%)	2	1-6	4-7	2
Compressive Strength (MPa)	90-250	100-200	-	-
Cure Shrinkage (%)	4-8	1-2	--	-
Water absorption 24 hr at 20^0C	0.1-0.3	0.1-0.4	-	-
Fracture Energy (kPa)	-	-	2.5	-

(Joseph et al., 1996). Composite manufacture can be achieved using low viscosity epoxy and phenolic resins that cure at room temperature. In addition epoxy resin does not produce volatile products during curing which is most desirable in production of void free composites. Therefore, although epoxy resins are relatively more expensive than polyester, they have potential for the development of high added value plant fibre composites, where long fibres at a high content are required. A comparative study of the advantages and disadvantages of thermosetting resins are display in Table 2.2.

2.3.1.1 Epoxy Resin

Epoxy resin is defined as a molecule containing more than one epoxide groups (Figure 2.2). The epoxide group also termed as oxirane or ethoxyline group and is shown below.

Table 2.2 Comparative study of the advantages and disadvantages of thermosetting resins (Rout, 2005)

Resin	Advantages	Disadvantages
Polyester	Easy to use, lowest cost of resins available (€ 1-2/kg)	Only moderate mechanical properties, high styrene emissions in open molds, high cure shrinkage, and limited range of working times
Vinyl ester	Very high chemical/Environmental resistance, high mechanical properties than polyesters	Postcure generally required for high properties, high styrene content, higher cost than polyesters (€ 2-4/kg), high cure shrinkage
Epoxy	High mechanical and thermal properties, high water resistance, low polymerisation shrinkages unlike polyesters during cure, excellent resistance to chemicals and solvents, long working time available	More expensive than vinyl esters (€ 3-15/kg), critical mixing, corrosive handling

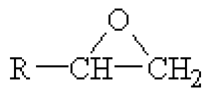

Figure 2.2 Epoxide Groups

These resins are thermosetting polymers and are used as adhesives, high performance coatings and potting and encapsulating materials. These resins have excellent electrical properties, low shrinkage, good adhesion to many metals and resistance to moisture, thermal and mechanical shock. The functional group in epoxy resins is called the oxirane, a three-membered strained ring containing oxygen. Epoxy resins, depending on their backbone structure, may be low or high viscosity liquids or solids. In low viscosity resin, it is possible to achieve a good wetting of fibres by the resin without using high temperature or pressure. The impregnation of fibres with high viscosity resins is done by using high temperature and pressure.

A wide range of starting materials can be used for the preparation of epoxy resins thereby providing a variety of resins with controllable high performance characteristics. These resins generally are prepared by reacting to a poly-functional amine or phenol with epichlorohydrin in the presence of a strong base. Diglycidyl ether of bisphenol-A (DGEBA) is a typical commercial epoxy resin and is synthesised by reacting bisphenol-A with epichlorohydrin in presence of a basic catalyst as shown in Figure 2.3.

Chemical structure of diglycidyl ether of Bisphenol A (DGEBA) shown in Figure 2.4. The presence of glycidyl units in these resins enhances the processability but reduces thermal resistance.

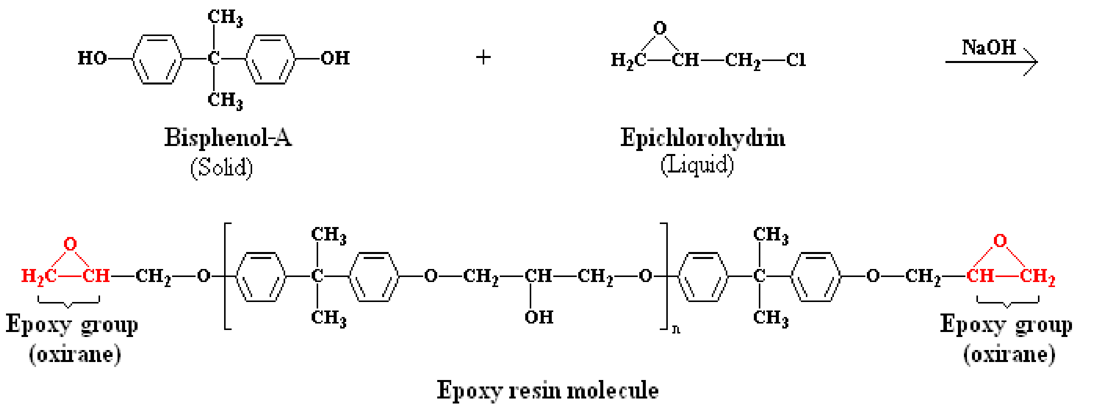

Figure 2.3 Reaction between bisphenol-A and epichlorohydrin to form epoxy resin

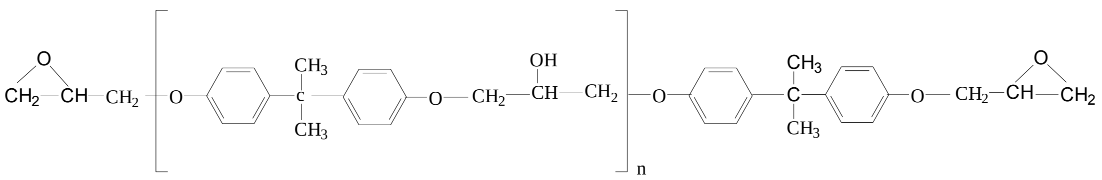

Figure 2.4 Diglycidyl ether of Bisphenol A

The most widely used curing agents for epoxy resins are primary and secondary amines. Advantages and disadvantages of different types of curing agents for epoxy resin are display in Table 2.3. During curing, epoxy resins can undergo three basic reactions.

1. Epoxy groups are rearranged and form direct linkages between themselves.

2. Aromatic and aliphatic -OHs link up to the epoxy groups.

3. Cross-linking takes place with the curing agent through various radical groups.

Mechanism of reaction between epoxy and curing agents are shown in Figure 2.5.

Table 2.3 Comparison of the properties of different types of curing agents for epoxy (Ratna, 2009)

Type	**Advantages**	**Disadvantages**
Aliphatic amine	Low cost, low viscosity, easy to mix , room temperature curing, fast reacting	High volatility, toxicity, short pot life, cured network can work up to 80 ^{0}C but not above
Cycloaliphatic amine	Room temperature curing, convenient handling, long pot life, better toughness, and thermal properties of the resulting network compared with aliphatic amine-cured network	High cost, can wok at a service temperature < 100 ^{0}C, poor chemical and solvent resistance
Aromatic amine	High Tg, better chemical resistance and thermal properties of the resulting network compared with aliphatic- and cycloaliphatic amine-cured network	Mostly solid, difficult to mix, Curing requires elevated temperature
Anhydride	High network Tg compared with amine curin agent, very good chemical and heat resistance of the resulting network	High temperature curing,long post-curing, necessity of accelerator, sensitive to moisture
DICY	Low volatility, improved adhesion, good flexibility and toughness	Difficult to mix, high temperature curing and long post-curing
Polysulfide	Flexibility of the resulting network, fast curing	Poor ageing and thermal properties, odour
Polyamides	Low volatility, low toxicity, room temperature-curing, good adhesion, long pot life, better flexibility and toughness of the resulting network compared with aliphatic amine-cured networks	Low Tg of the resulting network, high cost and high viscosity

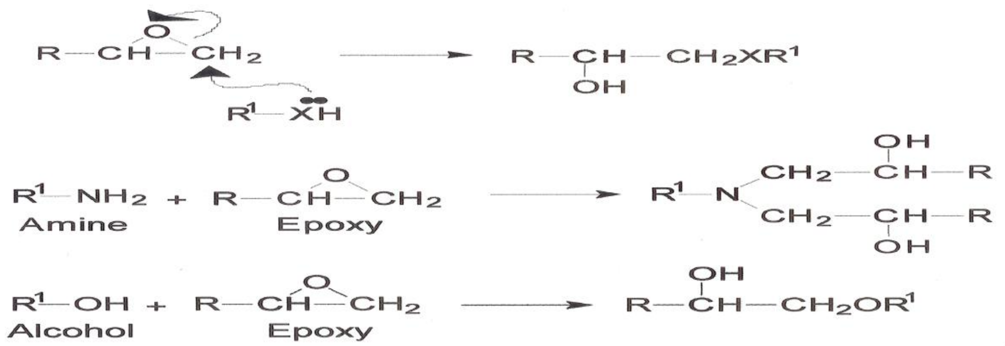

Figure 2.5 Mechanism of curing of epoxy resins

2.4 Reinforcement

2.4.1 Natural Fibre: Source, Classification and Applications

Natural fibres have been used as reinforcing materials for over 3,000 years. In recent years, natural fibres have been employed in combination with polymeric materials. The history of fibre reinforced plastics began in 1908 with cellulose fibre in phenolics, later extending to urea and melamine and reaching commodity status with glass fibre reinforced plastics. Cotton-polymer composites are reported to be the first fibre reinforced plastics used by the military for radar aircraft (Piggot, 1980, Lubin, 1982). One of the earliest examples (1950) was the East German Trabant car; the body was constructed from polyester reinforced with cotton fibres. However, over the past decade, cellulosic fillers of a fibrous nature have been of greater interest as they would give composites with improved mechanical properties compared to those containing non-fibrous fillers (Paramasivam and Abdul Kalam, 1974, Joseph et al., 1993b, Joseph et al., 1993a, Carvalho, 1997, Pavithran et al., 1987, Pavithran et al., 1988). Natural fibres can be sourced from plants, animals and minerals. Classification of the natural and synthetic fibres is shown in Figure 2.6. There is a wide variety of different fibres which can be applied as reinforcement or fillers.

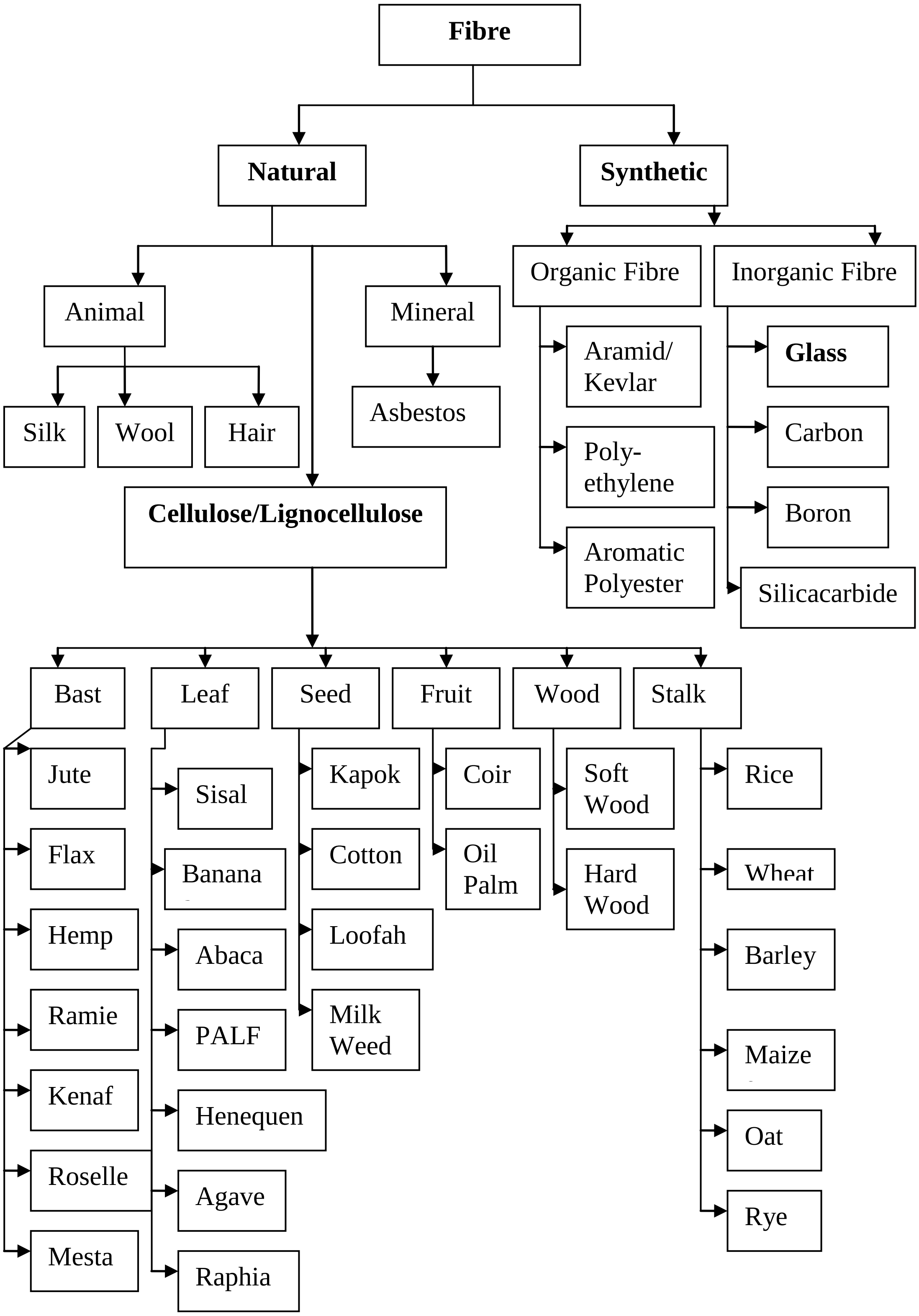

Figure 2.6 Classification of Natural and Synthetic fibres
Source: (Lilholt & Lawther, 2002,Rowell, 2008, Alexander Bismarck and Thomas, 2005)

All these lignocellulosic fibres consist of long cells with relatively thick cell walls which make them stiff and strong. In most of the fibre plants the cells are glued together into long thin fibres, the length of which is dependent on the length of the plant. The fibres may differ in coarseness, in the length of the cells and in the strength and stiffness of the cell walls. Since natural fibres are strong, light in weight, abundant, non-abrasive, non-hazardous and inexpensive, they can serve as an excellent reinforcing agent for polymeric materials. Natural fibres posses moderately high specific strength and stiffness and can be used as reinforcing materials in polymeric resin matrices to make useful structural composites material. Advantages and disadvantages of natural fibres are shown in Table 2.4.

Table 2.4 Advantage and disadvantages of Natural Fibres (Sreekumar, 2008)

Advantages	**Disadvantages**
Low specific weight results in a higher specific strength and stiffness than glass	Lower strength especially impact strength
Renewable resources, production require little energy and low CO_2 emission	Variable quality, influence by weather
Production with low investment at low cost	Poor moisture resistance which causes swelling of the fibres
Friendly Processing, no wear of tools and no skin irritation	Restricted maximum processing temperature
High electrical resistance	Lower durability
Good thermal and acoustic insulating properties	Poor fire resistance
Biodegradable	Poor fibre/matrix adhesion
Thermal recycling is possible	Price fluctuation by harvest results or agricultural politics

2.4.2 Chemical composition of natural fibres

Chemical composition of some natural fibres is shown in Table 2.5. Properties of natural fibres depend mainly on the nature of the plant, locality in which it is grown, age of the plant, and the extraction method used. For example, coir is a hard and tough multicellular fibre with a central portion called a "lacuna". Sisal is an important leaf fibre and is very strong. Pineapple leaf fibre is soft and has high

Table 2.5 Chemical composition of common lignocellulosic fibres

Fibre	Cellulose	Hemi-cellulose	Lignin	Extra-ctives	Ash Content	Water soluble	Researchers
Cotton	82.7	5.7	-	6.3	-	1.0	(Gassan and Bledzki, 1996)
Jute	64.4	12	11.8	0.7	-	1.1	(Gassan and Bledzki, 1996)
Flax	64.1	16.7	2.0	1.5-3.3	-	3.9	(Gassan and Bledzki, 1996)
Ramie	68.6	13.1	0.6	1.9-2.2	-	5.5	(Gassan and Bledzki, 1996)
Sisal	65.8	12.0	9.9	0.8-0.11	-	1.2	(Gassan and Bledzki, 1996)
Oil Palm EFB	65.0	-	19.0	-	2.0	-	(Abdul Khalil and Rozman, 2004)
Oil Palm Frond	56.03	27.51	20.48	4.40	2.4	-	(Abdul Khalil and Rozman, 2004)
Abaca	56-63	20-25	7-9	3	-	1.40	(John and Anandjiwala, 2008)
Hemp	74.4	17.9	3.7	0.9-1.7	-	-	(Bledzki et al., 1996)
Kenaf	53.4	33.9	21.2	-	4.0	-	(Abdul Khalil et al., 2010c)
Coir	32–43	0.15–0.25	40–45	-	-	-	Pillai and Vasudev,2001
Banana	60–65	19	5-10	4.6	-	-	(Reddy and Yang, 2005) (Cordeiro et al., 2004)
PALF	81.5	-	12.7	-	-	-	(Devi et al., 1997)
Sun hemp	41-48	8.3-13	22.7	-	-	-	(John and Anandjiwala, 2008)
Bamboo	73.83	12.49	10.15	3.16	-	-	(Wang et al., 2010)
Hard wood	31-64	25-40	14-34	0.1-7.7	<1	-	(Tsoumis, 1991)
Soft wood	30-60	20-30	21-37	0.2-8.5	<1	-	(Tsoumis, 1991)

cellulose content. EFB fibres are a hard and tough multicellular fibre with a central portion also called a “lacuna”. The porous surface morphology of EFB fibre is useful for better mechanical macromolecule itself (intramolecular) and between other cellulose interlocking with matrix resin for composite fabrication (Sreekala et al., 1997a). The elementary unit of a cellulose macromolecule is anhydro-d-glucose, which contains three alcohol hydroxyls (-OH) (Bledzki et al., 1996). These hydroxyls form hydrogen bonds inside the macromolecules (intermolecular) as well as with hydroxyl groups from the air. Therefore, all plant fibres are of a hydrophilic nature, their moisture content reaches 8-13% (Kuruvilla Joseph et al., 1999).

2.4.3 Physical Properties of Natural fibres

The properties of natural fibre vary according to shapes, sizes, orientations, thickness of the cell walls of individual fibres (Satyanarayana et al., 1990). It is better to know the length and width of the fibres for comparison between different natural fibre because fibre and width of the natural fibre play an important role for further application of these fibres. High aspect ratio is very important factor in composite fabrication because it gives us signs about its strength element (Han and Rowell, 1997). Fibre’s strength is an important factor to choose fibre that is specific for certain applications. Table 2.6 gives data on length and diameter of various fibres.

2.4.4 Mechanical Properties of Natural Fibres

As long as specific modulus of natural fibres (modulus per unit specific gravity) is considered, the natural fibres show values that are comparable to or even better than glass fibres. Natural fibres exhibit significantly better elongation at break which will translate in better composite damage tolerance. Low cost and better damage tolerance makes natural fibre attractive for housing construction with low load requirements. Among all the natural fibre reinforcing materials, jute appears to be a promising material because it is relatively inexpensive and commercially available in many of the required forms (Bhagawan et al., 1987). Wood is the most abundantly used natural cellulose fibre because of its extensive use in pulp and paper industries. However, for better strength and stiffness cellulose fibres like hemp, flax, jute, kenaf and sisal are becoming increasingly important in composites production. Table 2.7 shows the mechanical properties of commercially important fibre that could be utilized for composites.

Table 2.6 Physical properties of lignocellulosic fibres

Fibre	**Length of fibre (mm)**	**Diameter of Fibre (μm)**	**Reference**
Oil Palm EFB	0.89 - 0.99	19.1 – 25.0	(Mohamad et al., 1985, Law and Jiang, 2001)
Oil Palm Frond	1.52 -1.59	19.7	(Mohamad et al., 1985, Law and Jiang, 2001)
Oil Palm Trunk	0.96 -1.22	29.6 – 35.3	(Mohamad et al., 1985, Khoo and Year, 1985)
Coconut Husks	0.3 – 1.0	100 – 450	(Reddy and Yang, 2005)
Banana	0.17	13.16	(Ibrahim et al., 2010)
Pineapple Leaves	3 - 9	20 – 80	(Reddy and Yang, 2005)
Jute	0.8-6	5-25	(Rowell, 2008)
Sisal	0.8-8	7-47	(Rowell, 2008)
Flax	10-65	5-38	(Rowell, 2008)
Hemp	5-55	10-51	(Rowell, 2008)
Cotton	15-56	12-35	(Rowell, 2008)
Henequen	-	8-33	(Rowell, 2008)
Ramie	40-250	18-80	(Rowell, 2008)
Kenaf Kenaf	1.4-11	12-36	(Rowell, 2008)
(core)	0.4-1.1	18-37	(Rowell, 2008)
Bagasse	0.8-2.8	10-34	(Rowell, 2008)
Bamboo	2.7	14	(Olesen and Plackett, 1997)
Softwood	3.3	33	(Olesen and Plackett, 1997)
Hardwood	1.0	20	(Olesen and Plackett, 1997)

Table 2.7 Mechanical properties of commercially important fibre (Khalil et al., 2008, Franck, 2005, Bhagawan et al., 1987)

Fibres	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus(GPa)	Elongation at break (%)
Oil Palm EFB	0.7-1.55	248	3.2	2.5
Flax	1.4	800-1500	60-80	1.2-1.6
Hemp	1.48	550-900	70	1.6
Jute	1.46	400-800	10-30	1.8
Ramie	1.5	500	44	2
Coir	1.25	220	6	15-25
Sisal	1.33	600-700	38	2-3
Abaca	1.5	980	-	-
Cotton	1.51	400	12	3-10
Kenaf	1.2	295		2.7-6.9
Kenaf (core)	0.21	-	-	-
Bagasse	1.2	20-290	19.7-27.1	1.1
Henequen	1.4	430-580	-	3-4.7
Pineapple	1.5	170-1627	82	1-3
Banana	1.35	355	33.8	5.3

2.4.5 Oil Palm Empty Fruit Bunch Fibres

Elaeis guineensis (oil palm) is one of the most important plants in Malaysia, Indonesia and Thailand. Figure 2.7 show oil palm EFB and EFB Fibres. In Malaysia, oil palm is one of the most important commercial crops. Malaysia is the world's largest producer and exporter of the oil, accounting for approximately 50% of the world's oil and fat production. An estimation based on a planted area of 4.69 million ha (MPOB, 2009), and a production rate of dry oil palm biomass of 20.336 tonnes per ha per year (Lim, 1998), shows that the Malaysian palm oil industry produced approximately 95.3 million tonnes of dry lignocellulosic biomass in 2009. This figure is expected to increase substantially when the total planted hectarage of oil palm in Malaysia could reach 4.74 million ha in 2015 (Basiron & Simeh, 2005), while the projected hectarage in Indonesia is 4.5 million ha. Oil palm industries generate abundant amount of biomass say in million of tons per year (Rozman et al., 2005b) which when properly used will not only be able to solve the disposal problem