CHARACTERIZATION AND MODELING OF PULTRUDED JUTE FIBRE REINFORCED UNSATURATED POLYESTER COMPOSITE

by

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Thesis submitted in fulfillment of the requirements for the Degree of Master of Science

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DECLARATION

I declare that the content presented in this dissertation is my own work which was done at University Sains Malaysia unless informed otherwise. The dissertation has not been previously submitted for any other degree.

Saya isytiharkan bahawa kandungan yang dibentangkan di dalam disertasi ini adalah hasil kerja saya sendiri dan telah di jalankan di Universiti Sains Malaysia kecuali dimaklumkan sebaliknya. Disertasi ini juga tidak pernah disertakan untuk ijazah yang lain sebelum ini.

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Date: 2/8/2011

Witness:

Sign:

Supervisor's Name: Associate Professor Dr. Hazizan Md Akil

Date: 2/8/2011

DEDICATION

To my mum and dad....

For Everything...

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Sahnizam Safiee

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LIST OF ABBREVIATION

ASTM	American Society of Testing and Materials
2D	2 Dimension
3D	3 Dimension
Al	Aluminium
BMC	Bulk Moulding Compound
BPO	Butyl Peroxide
CaCo3	Calcium Carbonate
CAD	Computer Aided Design
CNC	Computer Numerical Control
CTE	Coefficient of Thermal Expansion
DMA	Dynamic Mechanical Analysis
DOF	Degree of Freedom
FE	Finite Element
FEA	Finite Element Analysis
FESEM	Field Emission Scanning Electron Microscope
FRP	Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
GMT	Glass-mat Thermoplastic
GRP	Glass Reinforced Polymer
GUI	Graphical User Interphase
h	Hour
LPMC	Low Pressure Moulding Compound
LSE	Least Square Elimination
MA	Major Ampullate
MEKP	Methyl etyl Ketone Peroxide
MEMS	Micro-electromechanical System
NF	Natural Fibre
Pbw	

PE	Polyetylene
PEEK	Polyetheretherketone
PJFRC	Pultruded Jute Fibre Reinforced Composite
PP	Polypropylene
PPS	Polyphenylene
RT	Room Temperature
RTM	Resin Transfer Moulding
SiC	Silicon Carbide
SMC	Sheet Moulding Compound
TBPB	Tertiary-Butyl Peroxybenzoate
Tg	Glass Transition Temperature
TMA	Thermal Mechanical Analyzer
USP	Unsaturated Polyester
VE	Vinyl Ester

LIST OF SYMBOLS

%	Percentage
°C	Degree Celcius
E	Young's Modulus
σ	Stress
ε	Strain
ρ	Density
US$	United State Dolar
C	Specific Heat
°F	Degree Fehrenheit
α	Coefficient of Thermal Expansion
G	Shear Modulus
υ	Poisson's Ratio
K	Kelvin
V_f	Volume frvaction

PENGKELASAN DAN PERMODELAN KOMPOSIT GENTIAN JUT TERPULTRISI DIPERKUAT POLIESTER TAK TEPU

ABSTRAK

Komposit Gentian Jut Terpultrisi diperkuat Poliester tak tepu (PJFRC) telah disediakan dan diuji secara berperingkat dalam kajian ini. Tiga pecahan isipadu PJFRC yang berbeza dengan 50, 60, dan 70% telah dihasilkan melalui kaedah pultrisi. PJFRC yang mengandungi 70% pecahan isipadu telah berjaya dihasilkan dan mempamerkan taburan gentian yang sekata. Pecahan isipadu melebihi 70% tidak dapat disediakan kerana gentian akan mengalami terikan yang kuat di permukaannya. Analisa yang dilakukan meliputi analisa mekanikal, analisa dinamik mekanikal, kekonduksian haba, dan analisa mekanikal haba. Dalam setiap satu analisa, arah penyusunan gentian dalam bahan komposit telah dibahagikan kepada memanjang dan melintang. Peningkatan dalam sifat-sifat mekanikal adalah kerana pemindahan tegasan antara gentian dan matriks yang efektif. Keputusan morfologi dilaksanakan melalui pemerhatian mikrograf bagi setiap ujian mekanikal yang dilakukan. Pada 60% dan 70% kandungan gentian jut, kekuatan tarikan meningkat dengan masing – masing sebanyak 0.06% dan 0.03% sementara modulus keelastikan dengan masing – masing meningkat sebanyak 0.01% dan 0.08%. Dengan meningkatnya isipadu pecahan gentian, ia dikatakan akan meningkatkan sifat mekanikal dan fizikal bagi spesimen PJFRC. Kesemua parameter ini akan digunakan untuk analisis selanjutnya menggunakan analisa elemen terhad. Program penganalisaan elemen terhad ini telah digunakan untuk menganggar pekali pengembangan haba pada dua arah gentian yang berbeza (memanjang dan melintang). Dengan menganggap simetri bagi komposit menggunakan susunan segiempat sama dalam mewakili setiap unit sel, sifat komposit telah dimodelkan melalui analisa elemen terhad menggunakan perisian ANSYS. Pekali pengembangan haba bagi komposit matrik polimer secara signifikannya dipengaruhi oleh ciri-ciri parameter di antarafasa. Analisa analitik bagi menganggar nilai CTE untuk arah memanjang dan arah melintang telah didapati daripada kajian terdahulu. Kesemua model tersebut digunapakai untuk menganggarkan nilai CTE bagi bahan komposit searah. Beberapa model yang digunakan adalah seperti model Van Fo Fy, model Schapery, model Chamberlain, model Schneider dan model Chamis. Keputusan pelbagai penyelesaian persamaan kepelbagaian elemen terhad bagi komposit yang berbeza telah dibandingkan dengan pelbagai keputusan dari kaedah analitik dan keputusan dari eksperimen. Kesemua model dan analisa elemen terhad adalah selari dengan data-data eksperimen bagi arah CTE yang memanjang. Walau bagaimanapun, keputusan bagi model Chamis dan analisa elemen terhad secara amnya berada lebih baik dan selari dengan data eksperimen berbanding kaedah-kaedah yang lain bagi semua pecahan isipadu gentian yang diselidiki.

CHARACTERIZATION AND MODELING OF PULTRUDED JUTE FIBRE REINFORCED UNSATURATED POLYESTER COMPOSITE

ABSTRACT

Pultruded Jute Fibre Reinforced Unsaturated Polyester Composites (PJFRC) was prepared and examined stage by stage in this study. Three different fibre volume percent of PJFRC with 50, 60 and 70% were prepared using the pultrusion technique. The PJFRC with 70% of fibre volume percent was successfully produced and displayed a homogeneous fibre distribution before having a high attrition to the fibre surface if the fibre volume percent more than 70%. Analysis was done by means of mechanical analysis, dynamic mechanical analysis, thermal conductivity and thermal mechanical analysis. In every analysis, the unidirectional composite material was determined in the longitudinal and transverse fibre direction. Improvement in properties suggests effective stress transfer between fibre and matrix. Morphological assessment was done through micrograph observation in every mechanical testing evaluation. At 60% and 70% of jute fibre loading, tensile strength improved by 0.06% and 0.03% respectively, while the modulus of elasticity improved at 60 and 70% with 0.01% and 0.08% respectively. Increasing of fibre volume percent is said to improve the mechanical and physical properties of the PJFRC specimens. All of these parameters were then used for further analysis using finite element analysis. The finite element analysis program was used in order to estimate the coefficient of the thermal expansion at two different directions (longitudinal and transverse). Considering symmetry of the composite using the square

array in representative unit cell, it was modeled for the Finite Element (FE) analysis using ANSYS software. The coefficient of thermal expansion of the considered polymer matrix composites were significantly affected by the parameters characterizing the interphase. The analytical analysis to predict the CTE values for the longitudinal and transverse direction was taken from the previous study. All of these models were used for predicting the CTE value for the unidirectional composite materials. Some of the models are Van Fo Fy model, Schapery model, Chamberlain model, Schneider model, and Chamis model. Results of various finite element solutions for different types of composites were compared with the results of various analytical methods and with the available experimental results. All of the models and finite element analysis are in good agreement with the experimental data for longitudinal CTEs, however Chamis and Finite Element results for transverse CTE were generally showed better agreement with the experimental data than the other methods for all the different fibre volume percent investigated.

CHAPTER 1

INTRODUCTION

1.1 General introduction.

In the past two decades, the used of plant fibres such as jute, sisal, kenaf, banana leaves, kapok for manufacturing industry have been the subject of extensive research (Bledzki and Gassan, 1999). Owing to the low prices and the steadily rising performance of technical and standard plastics, the application of natural fibres has come to a near-halt. More recently, the critical discussion about the preservation of natural resources and recycling has led to a renewed interest concerning natural materials with the focus on renewable raw materials. Among the natural fibres, jute fibre is considered to be the most promising material because of its availability in the required form and at a low cost processing. Moreover, jute based composites have already proven to be a potential material for various structural and non structural low load bearing capacity (Ahmed *et al.*, 2007). Jute belongs to the genus *Corchorus*, family Tiliaceae is an example of a number of woody-stemmed herbaceous dicotyledons grown in the tropic and subtropics, from the bast of whose stems fibre can be extracted (Lewin and Pearce, 1998).

Fibre-reinforced polymer (FRP) composites offer several advantages in relation to traditional materials, such as high specific strength, good corrosion resistance, low thermal conductivity and rapid component installation. Despite the great potential of these materials, two major disadvantages limit their acceptance in civil engineering applications: their lack of inherent ductility and the fact that their fibrous and anisotropic character makes the joining of structural components difficult. natural fibre-based FRP is still new especially a continuous FRP product compared to the synthetic fibre-based FRP. The complexities of FRP composite materials are due to the unknown features such as chemical compatibility, wettability, adsorption characteristics, and development of complex stress states resulting from differences in thermal and moisture expansion, have so far restricted their complete characterization. Understanding the behavior of composites related to the properties of fibre and matrix material is desirable not only for the practical purpose of predicting the properties of composites but also the fundamental knowledge required in developing new material.

Several techniques in FRP fabrications are like pultrusion, filament winding, and resin transfer moulding (RTM) was discovered to obtain large production of composite structures, using low cost facilities, tools and materials (Calabrese and Valenza, 2003). Pultrusion is one of the techniques that had becoming promising in recent years. Many investigations have been done on the pultrusion process using various types of reinforcements and resin (Van de Velde and Kiekens, 2001; Carlsson and Tomas Åström, 1998; Paciornik *et al.*, 2003; Angelov *et al.*, 2007). Pultrusion processing has shown a growth of interest because of its cost effectiveness for high volume production of constant cross section parts and offers continuous production of profiles.

Thermal expansion is an important parameter for characterization of different binding forces, lattice dynamics, bands and crystal structure of any solid. Many investigators have focused their attention to study these properties theoretically and experimentally at different temperatures. These studies were very important since these materials are used as structural materials for cryogenic use. Thermal expansion is the fractional change in the length of a body when heated or cooled through a given temperature range and usually it is given as a coefficient per unit temperature interval, either as an average over a stated range, or as a tangent to the expansion curve as a given temperature. The longitudinal and transverse coefficient of thermal expansion of the orthotropic unidirectional composites must be known for the design purposes. The CTE of composite properties can be experimentally measured which can be expansive and time consuming when evaluating many parameters and different material systems, or predicted using the thermal and mechanical properties of the constituents. Furthermore, as the result of increasing computer technology, numerical solution such as finite element analysis (FEA) is being used to determine the coefficient of the thermal expansion (CTE) of composite materials. The problem of relating effective properties of fibre reinforced composite materials to constituent properties has received considerable attention. There are many analytical models exist for predicting the effective coefficient of thermal expansion either longitudinal or transverse for unidirectional fibre reinforced composites with isotropic and anisotropic phases (Fo Fy and Savin, 1965; Fo-Fê, 1966; Schapery, 1968; Rosen and Hashin, 1970; Sideridis, 1994).

1.2 Problem Statement

Recently, there are only a few substantial researches in introducing the natural fibres in the composite fabrication. The idea of using the natural fibres as reinforced materials is because they have low density, exhibit high specific properties, non-abrasive nature, high level of filler loading, availability, renew ability and safe working environment compared to the synthetic fibres (Herrera-Franco and Valadez-González, 2004; Behzad and Sain, 2007). Pultrusion is one of the techniques to produce a composite with the fibre volume percent up to 50-70%. It can produce a constant cross section parts and offers continuous production of profiles comparing to other processing techniques.

Another crucial parameter in the design and analysis of composite structures is the Coefficient of Thermal Expansion (CTE). The thermal expansion response is correlated to the microstructure, the deformation of the matrix, and the internal stress conditions. The CTE prediction is very important in order to explain the abnormalities in the thermal expansion behaviors obtained experimentally. Since the CTE of polymer matrix is much higher than the fibres and the fibres often exhibit anisotropic thermal and mechanical properties, the stress induced in composites due to temperature change is very complex. For the purpose of calculating the CTE of unidirectional composites, analytical models have been developed by simple rules of mixtures to thermo elastic energy principles. When different models for the transverse and longitudinal CTE are compared, large discrepancies exist. Which model is to be used will be discussed in this study.

As a result of increasing computer technology, numerical solution like Finite Element Analysis (FEA) is widely used. The use of micromechanical model using FEA in predicting the longitudinal and transverse CTE direction is to reduce man power and cost consumption in the sense of making a prototype for a new material development. FEA has been proven to offer better accuracy than analytical models. For a better accuracy in determining the transverse and longitudinal CTE direction, the experiment was set up for several times. This will give an average data in order to get a precise value of CTE.

Thus, in this study, the CTE of composites were calculated by FEA using a representative unit cell with various analytical methods, and with the available experimental results. Also, the expansion behavior of different material systems with respect to fibre content was determined numerically. All of the numerical models and FEA results for the longitudinal and transverse CTE will be compared with the experimental data obtained.

1.3 Research Objectives

How to develop a high strength and predict the best CTE results of the PJFRC structures? This is the main question underlying the research presented in this thesis. In order to answer this question, the following objectives have been defined:

1) To produce FRP composite material using natural fibre pultruded profile with the high strength performance to provide in the construction applications;
2) To study the effect of the fibre volume fraction on the mechanical and thermal properties of the Pultruded Jute Fibre Reinforced Composite (PJFRC);
3) To measure, calculate and predict the longitudinal and transverse CTE using TMA, ANSYS simulation and existing models;

4) Identify the best method for predicting the CTE of the natural fibre-based composite and validate this through experimental investigation.

1.4 Outline of Thesis Structures

The following is a summary of the thesis structures.

Chapter 1: Contains the introduction to the project. It covers brief introduction about the research background, problem statements, research objectives and outline of the thesis structure.

Chapter 2: Contains the literature review. It covers brief explanations and classification regarding FRP composite materials, natural fibre-based FRP, types of composites fabrications for the continuous and non-continuous reinforcement. The Finite Element Analysis and its importance also described and a review about Coefficient of the Thermal Expansion (CTE).

Chapter 3: Contains the information about the materials specifications, samples preparations, experimental procedures and equipment used in this study. Method for calculating and predicting the CTE for the longitudinal and transverse direction is presented and validated with experimental measurement.

Chapter 4: Contains results and discussion of this study. Design philosophy and design methods are developed according to both numerical and analytical model results.

Chapter 5: Contains conclusions of the research and suggestions for future studies. It proposes to further study by incorporating the hybrid composites.

CHAPTER 2

2.1 Introduction to Composite Materials

Composites are combinations of two materials in which one of the materials, called the reinforced phase, is in the form of fibres sheets, or particles or are embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer as in Figure 2.1. Typically, reinforcing materials are strong with low density while the matrix is usually ductile or tough material. If the composite is designed and fabricated correctly, it combines the strength and the reinforcement with the toughness of the matrix to achieve the combination of desirable properties not available in any single conventional material.

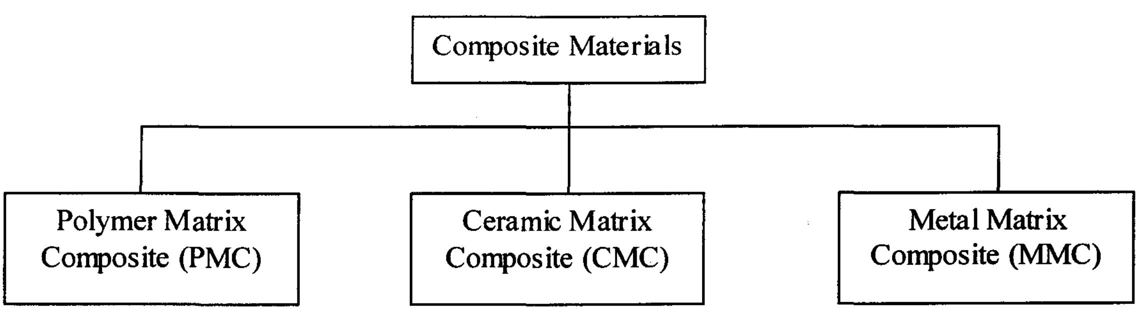

Figure 2.1: Classification scheme of composite materials.

Natural fibre such as jute, kenaf, sisal, kapok and several waste cellulosic products have been used as suitable alternatives to synthetic reinforcements for composites in many applications. The natural fibres offers more benefits such as less pollutant emission, low density, biodegradability, high specific properties and low cost production (Behzad and Sain, 2007; Joshi, Drzal *et al.,* 2004; Mohanty, Misra *et al.,* 2002). Many studies have been carried out to develop different manufacturing processes and to study the mechanical performances of natural fibre composites (Herrera-Franco and Valadez-González, 2004; Cantero *et al.,* 2003; Jacob *et al.,* 2004). Composite is a combination of two or more materials to exhibits a significant mechanical characteristic such as stiffness, toughness, and ambient and high temperature strength (Callister, 1999). There are also many numbers of composites that occur in nature. For example, wood consists of strong and flexible cellulose fibres surrounded and held together by a stiffer material called lignin. Classification of composite materials is based on of three main divisions; particle reinforced; fibre reinforced; and structural composites. Technologically, the most important composites are those in which the dispersed phase is in the form of a fibre.

Design goals of fibre-reinforced composites often include high strength and/or stiffness on a weight basis. These characteristics are expressed in terms of specific strength and specific modulus parameters, which correspond respectively to the ratios of tensile strength to specific gravity and modulus of elasticity to specific gravity. Fibre-reinforced composites with exceptionally high specific strength and moduli have been produced that utilize low-density fibre and matrix materials. As shown in Figure 2.2, fibre-reinforced composites are sub classified by fibre length. For short fibre, the fibres are too short to produce a significant improvement in strength.

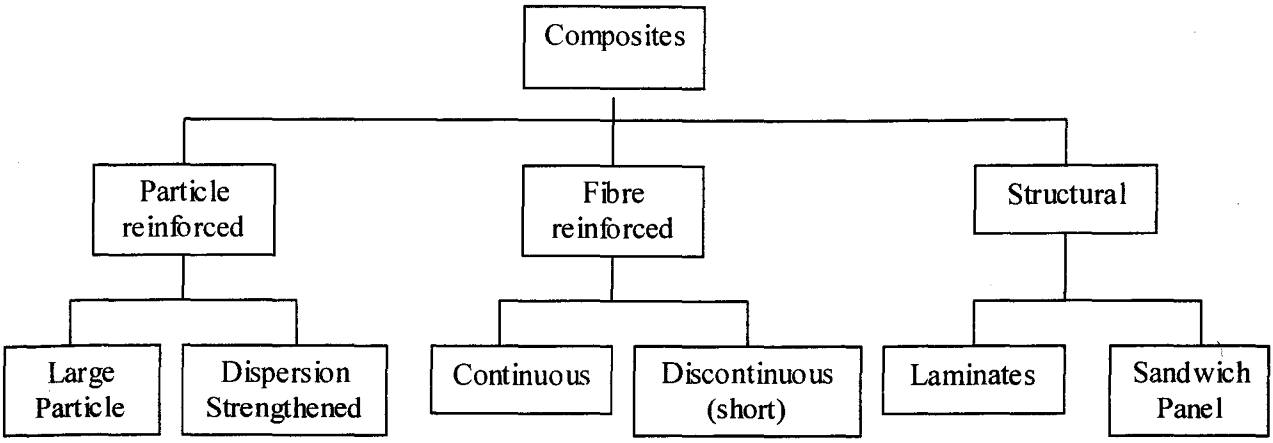

Figure 2.2: A classification scheme for the various polymer reinforced composite types

2.2 Fibre Reinforced Polymers (FRP)

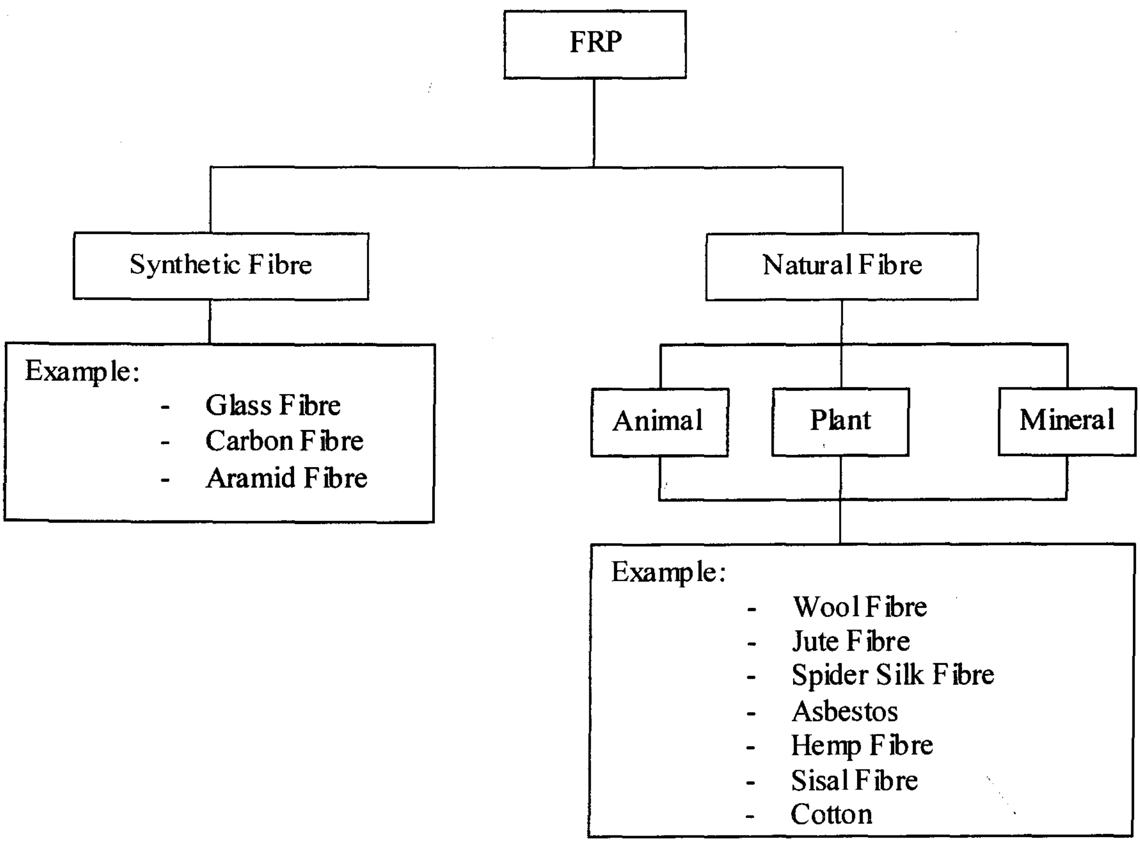

Figure 2.3: Deviation of Fibre Reinforced Polymer (FRP) commonly used in composite application (Ritchie *et al.,* 1991; George *et al.,* 2001; Bakis *et al.,* 2002).

Fibre Reinforced Polymer comprises of two different types namely synthetic and natural fibres as shown in Figure 2.3. Nowadays, the composite fabrication were commonly based on the synthetic fibre due to the high mechanical strength, corrosive and chemical resistance, high durability and many more as mentioned by many researchers (Ahmed *et al.*, 2007; Joshi *et al.*, 2004; Wonderly *et al., 2005*; Wambua *et al.*, 2003; Paciornik *et al.*, 2003). But as industry attempts to lessen the dependence on synthetic fibre reinforced composite, there is an increasing need to investigate and explore more environmentally friendly, sustainable materials to replace the existing fibre. With this highly concern, natural fibre reinforced composite were introduced as early as 1908 (Bledzki and Gassan, 1999). The types of natural fibre can be divided into 3 groups; animal fibre, plant fibre, and mineral fibre as shown in Figure 2.3. Agricultural crop from plantation are greatly produced in billion of tones around the world represent an abundant, inexpensive, and readily available sources of natural fibre reinforced composites. Among these enormous amounts of agricultural crops, only a minor quantity of residue is reserved as animal feed or household fuel and the major portion of the straw is burned in the field creating the environmental pollution (Sain and Panthapulakkal, 2006). The exploration of these inexpensive agricultural crops for making industrial composite products will open a new avenue for the utilization of agricultural crops by reducing the need for disposal and environmental deterioration through pollution, and at the same time add value to the creation of rural agricultural based economy.

2.2.1 Synthetic Fibre

2.2.1.1 Glass Fibre Reinforced Polymers (GFRP)

Glass fibre has seen limited usage in the construction and building industry for decades (Chambers, 1965; Halloway and Robinson, 1981; Green, 1987). This is because of the need to repair and retrofit the rapidly deteriorating infrastructure in recent years, the potential for using glass fibre reinforced composites become popular in a wide range of applications recently (Barbero and GangaRao, 1991). Glass fibre materials exhibit better resistance to environmental agents, and fatigue as well as the advantages of high stiffness to weight and strength to weight ratios compared to other synthetic fibres (Liao, *et al.,* 1999). Many researchers reported that the construction industry recently had focused on lower cost glass reinforcement rather than the carbon fibre reinforced in the aerospace applications.

Glass fibre is a material made from extremely fine fibre of glass. It is used as reinforcing agent for many polymer products, and resulting in a composite material properly known as glass-reinforced polymer (GRP). It is formed when thin strands of silica-based or other formulation glass is extruded into many fibres with small diameters suitable for the textile fabrication. The technique of heating and drawing glass into fine fibres has been known for millennia; however, the use of these fibres for textiles applications is more recent. The mechanical properties of the glass fibre and other synthetic fibres can be seen in Table 2.1.

Table 2.1: Some mechanical properties of synthetic fibre (Andrews *et al.*, 1997; Wonderly *et al.*, 2005).

	Fibre Glass	Carbon	Aramid (Kevlar 149)
Elastic Modulus, E (GPa)	79	230	160
Tensile Stress, σ (GPa)	2.4	4.9	1.7
Tensile Strain, ε (%)	3.04	2.1	1.0
Density, ρ (g/cm^3)	2.5	1.8	1.47
Fibre Diameter (μm)	15	7	12.4

2.2.1.2 Carbon Fibre

Carbon fibre is a material consisting of extremely thin fibres about 0.005-0.010 mm in diameter and composed mostly of carbon atoms. The carbons atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long exist of the fibre. The crystal alignment makes the fibre very strong for its size. Several thousand carbon fibre are twisted together to form a yarn, which maybe used by itself or woven into a fabric. Carbon fibre has many different weave patterns and can be combined with plastic resins and wound or molded to form composite materials such as Carbon Fibre Reinforced Polymer (CFRP) to provide a high strength to weight ratio material. The density of carbon fibre is considerably lower that the density of steel, making it ideal for applications requiring low weight. The properties of carbon fibre such as high tensile strength, low weight and low thermal expansion make it popular in aerospace, civil engineering, military and motorsports along with other competition sports. However, it is relatively expansive when compared to similar materials such as fibreglass. Carbon fibre is very strong when stretched or bend, but weak when compressed or exposed to a high impact.

2.2.1.3 Aramid Fibre

Aramid fibre is an attractive organic fibre with the combination of stiffness, high strength, high fracture strength, and having a low density (Liu *et al.,* 2008). Advanced composites made from aramid fibres have comparable axial properties like inorganic fibre-reinforced composites as well as significant reduction in weight. Aramid fibres have poor interfacial bonding with most of the commercially available resins used in composite because of its inertia surface, high crystallization, and poor off-axis strength. The carbon fibres are used in aerospace and military applications, for ballistic rated body armor fabric and ballistic composites, in bicycle tires, and as an asbestos substitute. The name is a shortened form of "aromatic polyamide". They are fibres in which the chain molecules are highly oriented along the fibre axis, so the strength of the chemical bond can be exploited.

2.2.2 Natural Fibre

Natural fibre (NF) is a class of hair-like materials that is in continuous filaments or is in discrete elongated pieces, similar to pieces of thread. It can be spun into filaments, thread, or rope. It can be used as a component of a composite material. Natural fibres can be found from 3 sources like; animals, vegetables and minerals (Joshi *et al.,* 2004). Most common natural fibres used in composite applications are from vegetables like jute, kenaf, sisal, coir, kapok, flax, ramie, and many more (Bledzki and Gassan, 1999). NF-reinforced polymers has started to be used in the application area as a construction material for the interior and exterior automotive parts and trenchless rehabilitation of underground pipes as reported by (Graupner *et al.*, 2009) and (Yu *et al.*, 2008).

Theoretically, the natural fibre is a single fibre of all plant based natural fibres consists of several cells. These cells are formed out of crystalline microfibrils based on cellulose, which are connected to a complete layer, by amorphous lignin and hemicellulose. Multiple of such cellulose-lignin/ hemicellulose layers in one primary and three secondary cell walls stick together to a multiple layer composites (Bledzki and Gassan, 1999). Unlike the traditional engineering fibres, e.g. glass and carbon fibres, these lignocellulosic fibres are able to impart the composite certain benefits such as: low density; less machine wear than that produced by mineral reinforcements; no health hazards; and a high degree of flexibility. The later is especially true because these fibres unlike glass fibres will bend rather than fracture during processing. Whole natural fibres undergo some breakage while being intensively mixed with the polymeric matrix, but this is not as notorious as with brittle or mineral fibres (Herrera-Franco and Valadez-González, 2004).

2.2.2.1 Animal Fibre

Wool Fibre

Wool fibre is usually restricted to describing the fibrous protein derived from the specialized skin cells called follicles in sheep. It has several qualities that distinguish it from hair or fur; it is crimped. It has a different texture or handle, it is elastic, and it is grown in staples. It consists of elongated cortical cells surrounded by overlapping cuticle cells. The outer layer of the cuticle cells is a surface membrane 5-7 nm thick, commonly referred to as the epicuticle (Bradbury, 1973). The wool fibre surfaces remain hydrophobic even after repeated solvent extraction. The hydrophobic surface can be modified using alcoholic alkali conditions (Lindberg, 1953). The dramatic reduction of the hydrophilicity of wool fibre can be observed after the surface treatment, which is attributed to the removal of the postulated lipid layer from the fibre surface. Global wool production is about 1.3 million tons per year, of which 60% is going into apparel. Australia is the leader of producing the wool in the world. New Zealand becomes the second largest wool producer, and become the largest producer of crossbred wool in the world. A nano structure of the wool fibre is shown in Figure 2.4.

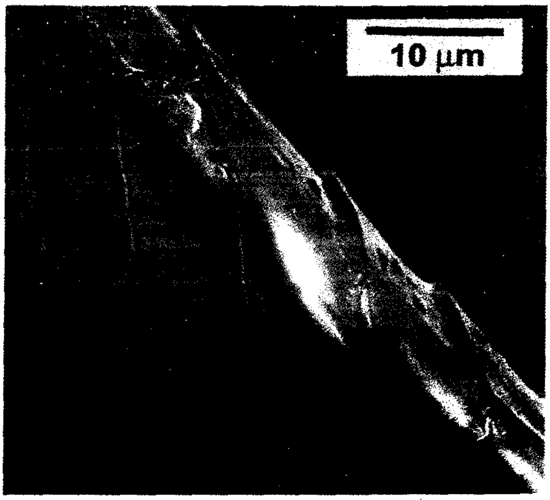

Figure 2.4: Nano-structure of wool fibre (Crossley *et al.*, 2000).

Spider Silk Fibre

Spider silk also known as gossamer, is a protein spun by spiders. Spiders use their silk to make webs or other structures, which function as nets to catch other animals. It combined good tensile strength and high extensibility (S.A. Fossey, 1999). Contrarily, most manmade fibre exhibit high tensile strength and stiffness or low strength and high extensibility. (Glisovic *et al.,* 2007) reported that the relationship between structure and mechanical properties is still not well understood, in particular, since the structural organization of the fibres is still somewhat controversial. From the previous report by (Zhengzhong *et al.,* 1999), the major ampullate (MA) dragline silk of spiders is thought to be in semi-crystalline, non-linear and viscoelastic biopolymers. Under a normal work load, this high performance fibre demonstrates good toughness, a relatively high ultimate tensile strain and high strength. The mechanical properties of silk are, however greatly influenced by water (Vollrath and Edmonds, 1989). It consists of complex protein molecules. Spider silk is remarkably strong material. Its tensile strength is superior to that of high grade-steel, and as strong as aramid filaments such as twaron and Kevlar. Most importantly, the silk fibre is very lightweight. It is also very ductile and is be able to stretch up to 140% of its length without breaking. It can hold its strength below - 40°C. This will exhibit a very high toughness, which equal to the commercial filaments, which themselves are the benchmarks of modern polymer fibre technology. Micro-Morphological study on spider dragline silk already shows that it differs significantly from the silk of moth (Kaplan *et al.,* 1994);(Vollrath *et al.*, 1996). (Beckwitt *et al.*, 1998), reported that spider silk are also interesting as members of a class of unusual protein; highly repetitive in sequence, and composed of a limited range of amino acid.

2.2.2.2 Plant Fibre

Kenaf Fibre

Kenaf (Hibiscus Kannabinus L) is being increasingly cultivated in Greece, where yield of fresh biomass range from 52.3 to 88.9 tha^{-1}, corresponding to the dry mass of

13.3 to 24.0 tha^{-1} (Alexopoulou *et al.,* 2000). The shoot constitutes 51-79% of the fresh weight of the plant (McMillin *et al.,* 1998), and about 25-40% from the total fibres is derived from the bark and 60-75% is from the cortex (Sellers *et al.*, 1993). (Kaldor *et al.,* 1990) and (Webber III, 1993) reported that kenaf is used for the production of high quality papers, animal feeds and many industrial applications. (Pill *et al.,* 1995) also reported that kenaf core is proposed as a constituent of growth media for tomato plant. The suitability of kenaf core for the growth media is depending on the size and percentage of kenaf in relation to the other components of the media (WebberIII *et al.,* 1999). Another study from (Pill and Bischoff, 1998) reported that enrichment with nitrogen may also be required to avoid growth suppression, possibly due to microbial immobilization within the kenaf. The failure of bulk production of kenaf for paper application stimulated research into other industrial applications such as fibre boards, composites, insulation mats and absorption particles. Figure 2.5 to Figure 2.7 and Table 2.2 represent the micrograph and optical kenaf fibre characteristics.

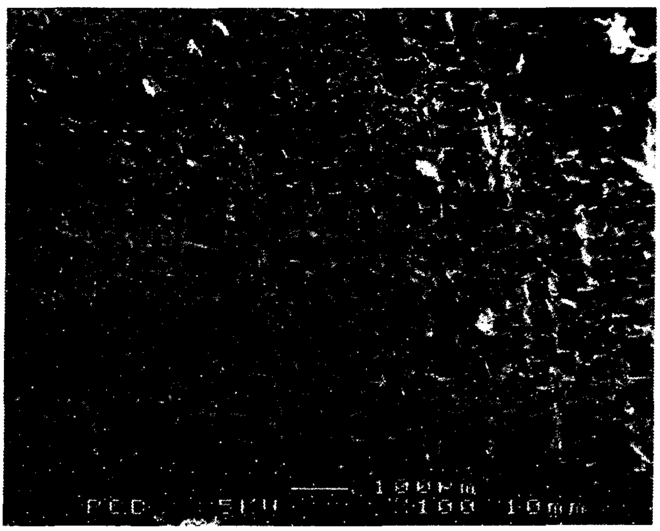

Figure 2.5: Transverse section of kenaf core with small hollow fibres and large water transport vessel (Lips *et al.,* 2009).

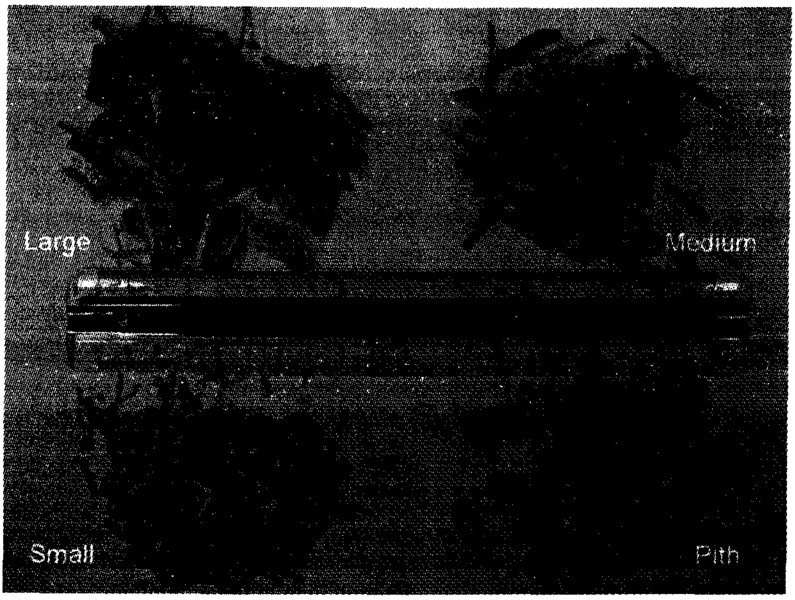

Figure 2.6: Different size of kenaf core and kenaf pith

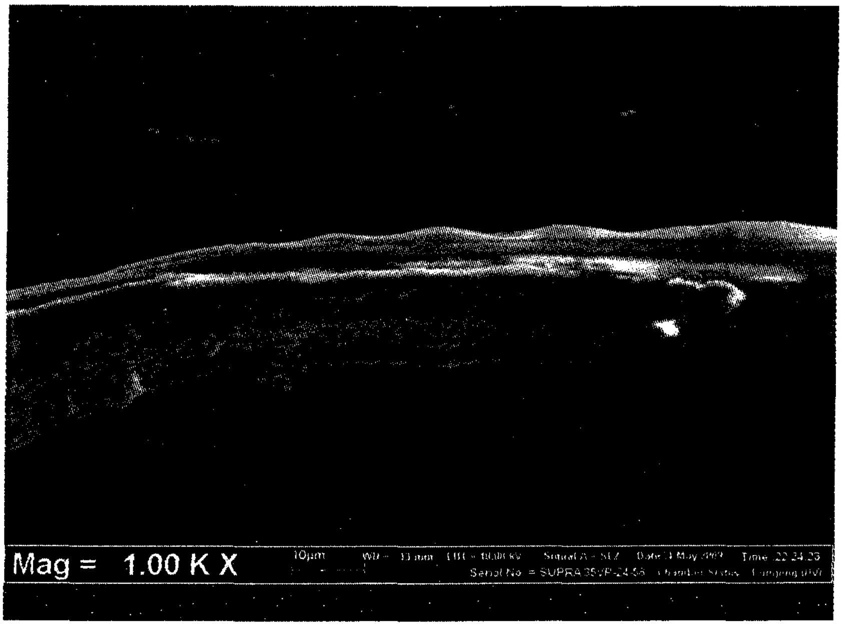

Figure 2.7: Kenaf single fibre under microscope observation

Table 2.2: Properties of Kenaf bast and core fibres (Villar *et al.,* 2009).

Property	Fibre	
	Bast	Core
Fibre length (mm)	2.55	0.74
Fibre diameter (μm)	20.5	37
Wall thickness (μm)	6.3	1.7
Holocellulose (%)	73.6	71.8
Lignin (%)	8.6	17.6
Pentosans (%)	15.6	20.6
Ash (%)	6.4	3.6

Hemp Fibre

Flax (Linum usitatissinum L.) and hemp (Cannabis Sativa L.) are annual bast fibre plants, the stems of which consists of surface layers, a bark layer with 20-50 bast fibre bundles, and a woody core with a central lumen. (Kymaelaeinen and Sjöberg, 2008) reported that the bast fibres are used as a raw material for the thermal insulation. They also reported that the sawdust like-shive that is produced from the core of the stems has been used as a thermal insulation especially in old buildings. Flax and hemp (Figure 2.8) are traditionally used in insulation tapes between timbers, but during the past decades, several types of mats have been developed into commercial products.

It has been reported that in 2001, France and German is the largest hemp product manufacturer in Europe especially for the insulation applications (Kymaelaeinen and Sjöberg, 2008). According to (Bledzki and Gassan, 1999), the properties of flax fibre are noticeably affected at temperature of about 170 °C. (Xue *et al.,* 2009) claims that the high temperatures (170°C-180°C) , to which fibre bundle are probably subjected during fibre processing and composite manufacturing do not induce significant effect to the tensile properties if the temperature are maintained less then 1h. (Mieck and Nechwatal, 1995) reported that the major damage will occurs to the flax fibre after exposure time more than 4 minutes at temperature above 240°C. The mechanical properties of some natural fibres are shown in Table 2.3.

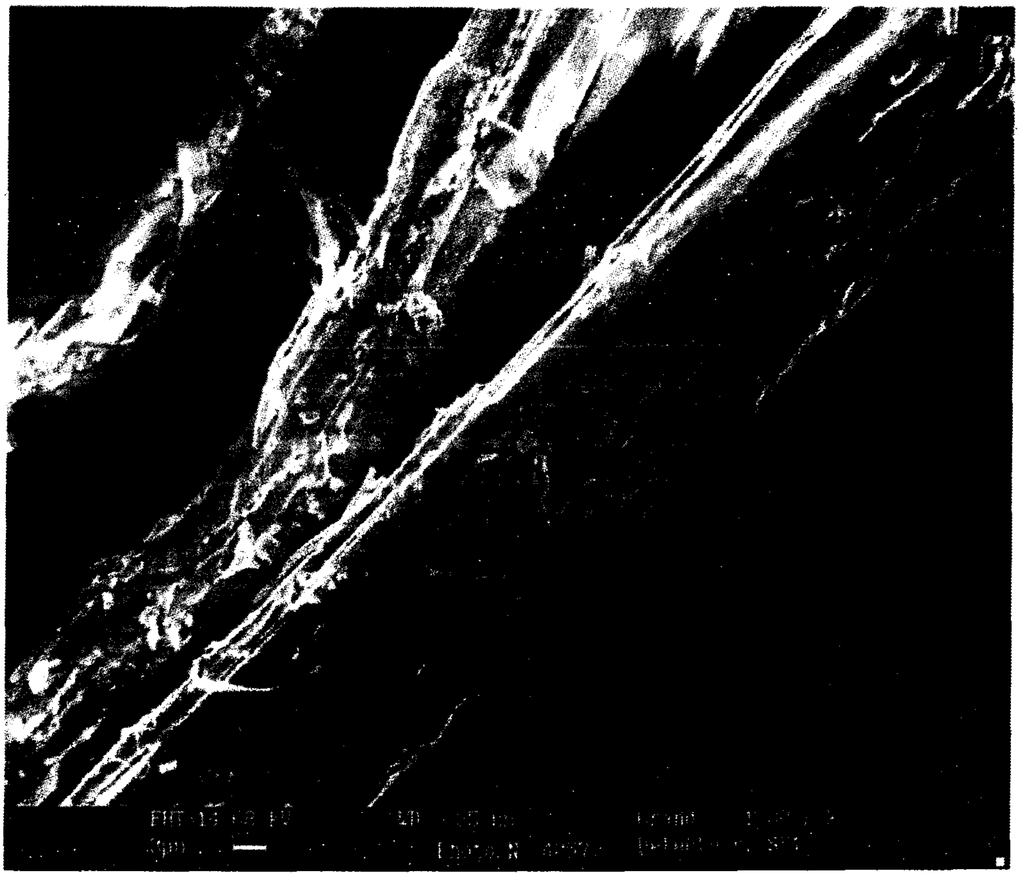

Figure 2.8: A bundle of hemp fibre (Vincent Placet, 2009)

Table 2.3: Mechanical properties of certain natural and synthetic fibres (Bismack *et al.*, 2005)

	Density (g/cm^3)	Diameter (μm)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
Flax	1.5	40-600	345-1500	27.6	2.7-3.2
Hemp	1.47	25-500	690	70	1.6
Jute	1.3-1.49	25-200	393-800	13-26.5	1.16-1.5
Kenaf			930	53	1.6
Ramie	1.55	-	400-938	61.4	1.2-3.8
Nettle			650	38	1.7
Sisal	1.45		468-700	9.4-22	3-7
EFB	0.7-1.55	150-500	248	3.2	25
Cotton	1.5-1.6	12-38	287-800	0.5	7-8
Coir	1.15-1.46	100-460	131-220	4-6	15-40
E-glass	2.55	<17	3400	73	2.5
Kevlar	1.44		3000	60	2.5-3.7
Carbon	1.78	5-7	3400-4800	240-425	1.4-1.8

Sisal Fibre

Sisal fibre is one of the most widely used plant fibres. It can be obtained from the leave of Agave Sisalana plant, which is largely available in tropical zone country (Sangthong *et al.,* 2009). From the fact, nearly 4.5 million tons of sisal fibres are produced every year throughout the world. Brazil and Tanzania are the largest Sisal producer in the world (Li *et al.,* 2000). Similar to the other plant fibre, sisal is becoming a great importance and raised a great interest to be used as an economical and environmentally friendly reinforcement for the polymeric material. A sketch of sisal plant is shown in Figure 2.9 and the sisal fibre was extracted from the sisal plant.

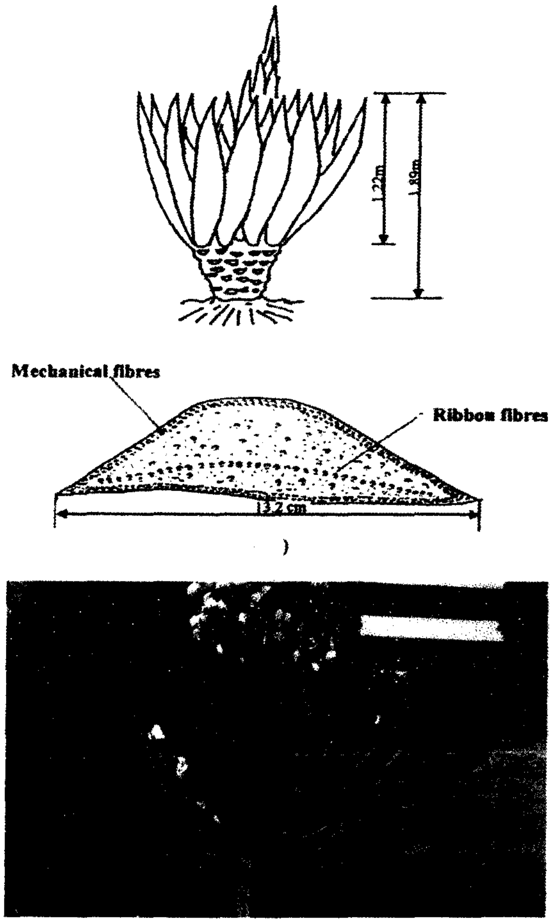

Figure 2.9: Sisal fibre from sisal plant.

Table 2.4: Some of the chemical properties of sisal fibre (Li *et al.*, 2000)

Properties	Quantity (%)
Cellulose	78
Lignin	8
Hemi Cellulose	10
Wax	2
Ash	1

Sisal-based composite materials are strong enough to be used as load bearing structural members in application such as structural panels, impact and blast resistance, repair and retrofit , earthquake remediation, strengthening of unreinforced masonry walls, and beam column connections (Flávio de Andrade Silva, 2009). Some of the chemical properties of Sisal fibre are shown in Table 2.4.

2.3 Martix Resins

2.3.1 Thermoplastic Resins

Thermoplastic matrix materials are generally tougher than most thermosets resins and offer the potential of improved hot/ wet resistance. Thermoplastic polymer can be remelt and remold when heated (Lubin and Peters, 1998). They are also the only matrices material currently available that allow thermoforming and other forms of rapid manufacturer because of their high strains to failure. The thermoplastics resin materials included polyether ether ketone (PEEK), polypropylene (PP), polyethylene (PE), polyether ketone ketone (PEKK) and others. Most thermoplastic matrices do not absorb any significant amount of water, but organic solvent resistance is an area of concern for the non-crystalline thermoplastics. Thermoplastic matrix fabrication offers a lower cost production because of the potential of being remolded by applying heat and pressure. Thermoplastic composites are deemed to be a mature technology and will compete with other plastic composite on the properties and cost basis.

2.3.2 Thermosetting Resins

Thermosetting is an irreversible cures polymeric materials. The cure could be done by heat, chemical reaction and irradiation such electron beams bombardment (Goodman, 1998). Thermosetting resins are usually liquid or malleable prior to curing and designed to be molded into their final form, or used as adhesive. Engineering thermosets have higher mechanical properties, lower resistance to temperature, higher coefficients of expansion, and low cost commodity like production and sales. Specialty thermosets are useful because of one or more highly specific and unusual property which offsets any lack of other properties. The individual family of plastics can be loosely classed as shown in Table 2.5.

Table 2.5 Classification of thermoplastic for several uses (Goodman, 1998).

Use	Thermoset
General Purpose	Phenolic, animos, polyester
Engineering	Epoxy, polyurethane
Specialty	Silicones, allyls, high temperature thermosets, cross linked thermoplastics

2.4 Composites Application

The discipline of composite technology application, whether through manufacture or product acceptance for example, has extended virtually at every corner of the world. The total 1998 output of that world-wide industry has been estimated as 5.5 x 106 tonnes, valued at US$143x109, rising respectively to 7.0 x 106 tonnes and US$205 x 109 by 2005 (Starr, 2000). There are some reasons for the wide acceptance composites by the