CHAPTER 2

LITERATURE REVIEW

2.1 OVER VIEW ON THE NATURAL FIBER COMPOSITES

In recent years, the interest of scientists and engineers has turned over on utilising plant fibers as effectively and economically as possible to produce good quality fiber-reinforced polymer composites for structural, building, and other needs. It is because of the high availability and has led to the development of alternative materials instead of conventional or man-made ones. Many types of natural fibers have been investigated for their use in polymer such as wood fiber (Maldas et al 1995), sisal (Joseph et al 1999), kenaf (Rowell et al 1999), pineapple (Mishra et al 2001), jute (Mohanty et al 2006), banana (Pothan et al 2003) and straw (Kamel 2004).

Bax and Mussig 2008 investigated the mechanical properties of PLA reinforced with cordenka rayon fibers and flax fibers, respectively. A poor adhesion was observed using Scanning electron microscopy analysis. The highest impact strength and tensile strength were found for cordenko reinforced PLA at fiber proportion of 30%.

Mwaikambo and Ansell 2003 evaluated the physical and mechanical properties of the natural fiber composites to assess their serviceability. Treated fibers with highest strength were used as reinforcement for cashew nut shell liquid matrix and determined tensile properties, porosity and also examined fracture surface topography of the composites. The objective was to maximize the amount of low cost natural fiber resource in the composite. They concluded that the presence of lignin in the untreated hemp fiber offers additional cross linking sites and the untreated fiber surface is more compatible with CNSL (Cashew Nut Shell Liquid resin) than alkali treated surface.

Natural fibers are derived from plants, animals and mineral sources. They can be classified according to their origin as depicted in Figure 2.1. The use of natural fibers as industrial components improves the environmental sustainability of the parts being constructed, especially the automotive market. In the building industry, the interest in natural fibers is mostly economical and technical; natural fibers allow insulation properties higher than current materials. Table 2.1 presents few of the most used natural fibers' name, family name and scientific name. Although, the annual production of natural fibers outweighs that of animal or mineral fibers, all have long been useful to human. The annual productions of some natural fibers are given in Table 2.2. The properties of natural fibers depend mainly on the nature of the plant, locality in which it is grown, age of the plant, and the extraction method used (Joseph et al 1999, Khandal et al 2011 and Kuchinda et al 2001). The physical properties of natural fibers were mainly determined by their chemical and physical composition, such as, structure of fibers, cellulose content, angle of fibrils, cross section and the degree of polymerization (Idicula et al 2005). Tables 2.3 and 2.4 shows the properties and chemical compositions of some of the natural fibers respectively.

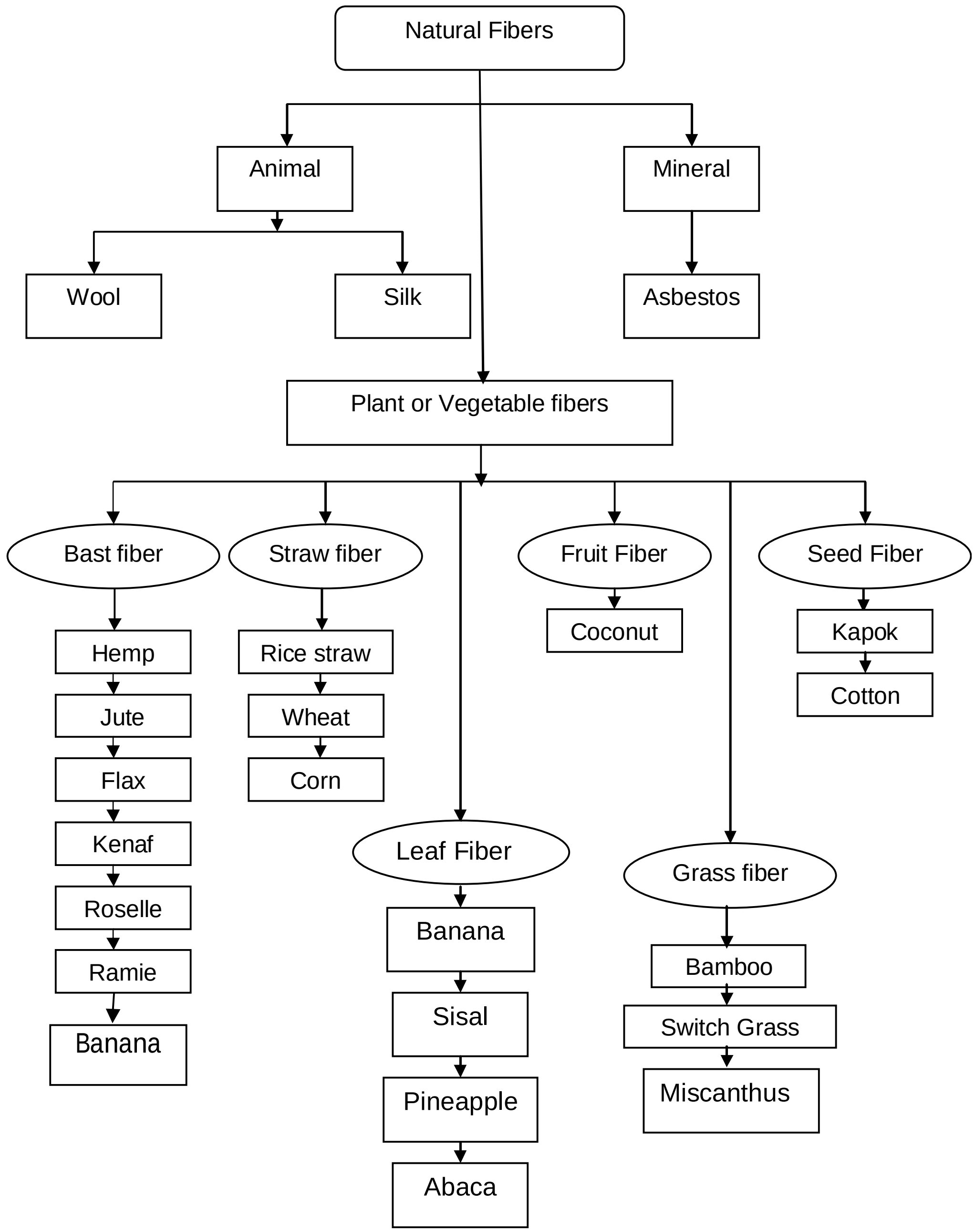

Figure 2.1 Classification of natural fibers

Table 2.1 Fibers and their types, family and scientific names

Common Name	Scientific Name	Fiber	Family	Native Region	Uses
Flax	Linum usitatissimum	Bast (stem)	Linaceae	Eurasia	Linen fabrics, seed oil
Ramie	Boehmeria nivea	Bast (stem)	Urticaceae	Tropical Asia	Textiles (blended with cotton), paper, cordage
Hemp	Cannabis sativa	Bast (stem)	Cannabaceae	Eurasia	Cordage, nets, paper
Jute	Corchorus capsularis, Corchorus olitorius	Bast (stem)	Tiliaceae	Eurasia	Cordage, burlap bagging
Kenaf	Hibiscus cannabinus	Bast (stem)	Malvaceae	Africa, India	Paper, cordage, bagging, seed oil
Sun hemp	Crotalaria juncea	Bast (stem)	Fabaceae	Central Asia	Cordage, high-grade paper, fire hoses, sandals
Urena	Urena lobata, Urena sinuata	Bast (stem)	Malvaceae	China	Paper, bagging, cordage, upholstery
Sisal	Agave sisalana	Hard (leaf)	Agavaceae	Mexico	Cordage, bagging, coarse fabrics
Abacá	Musa textilis	Hard (leaf)	Musaceae	Philippines	Marine cordage, paper, mats
Kapok	Ceiba pentandra	Fruit trichome	Bombacaceae	Pantropical	Upholstery padding, flotation devices
Coir	Cocos nucifera	Fruit fiber	Aracaceae	Pantropical	Rugs, mats, brushes

Table 2.2 Annual productions of natural fibers and sources (Mwaikambo 2006)

Fiber type	Origin	World Production 10^3 Tons
Coir	Fruit	100
Banana	Stem	200
Bamboo	Stem	10,000
Jute	Stem	2,500
Hemp	Stem	215
Flax	Stem	810
Abaca	Leaf	70
Kenaf	Stem	770
Roselle	Stem	250
Ramie	Stem	100
Sisal	Leaf	380
Sun Hemp	Stem	70
Cotton Lint	Fruit	18,500
Wood	Stem	1, 750,000

Table 2.3 Mechanical properties of some natural fibers (Joseph et al 1999)

Type of fibers	**Density (kg/cm^3)**	**Elongation at break (%)**	**Tensile strength (MPa)**	**Young's modulus (GPa)**
Cotton	1.5-1.6	7.0-8.0	287-597	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp	-	1.6	690	-
Ramie	-	3.6-3.8	400-938	61.4-128
Sisal	1.5	2.0-2.5	511-635	9.4-22.0
Coir	1.2	30.0	175	4.0-6.0
Silk	-	20-25	252-528	7.32-11.22
Banana	1.3	7	500	1.4
Wool	-	25-35	122-175	2.34-3.42
Bagasse	1.25	-	290	17
Bamboo	1.5	3	575	27
Kneaf	-	-	295	22
Elephant grass	-	5	178	5.6

Table 2.4 Chemical compositions of natural fibers

Fiber type	Cellulose (wt %)	Hemicellulose (wt %)	Lignin (wt %)	Pectin (wt %)	Moisture content (wt %)	Waxes (wt %)	Micro fibrillar angle (Degree)
Flax	71	18.6-20.6	2.2	2.3	8-12	1.7	5-10
Hemp	70-74	17.9-22.4	3.7-5.7	0.9	6.2-12	0.8	2-6
Jute	61.1-71.5	13.6 -20.4	12-13	0.2	12.5-13.7	0.5	8
Kenaf	45-57	21.5	8-13	3-5	--	--	--
Ramie	68.6-76.2	13.1-16.7	0.6-0.7	1.9	7.5-17	0.3	7.5
Nettle	86	--	--	--	11-17	--	--
Sisal	66-78	10-14	10-14	10	10-22	2	10-22
PALF	70-82		5-12.7		11.8	--	14
Banana	63-64	10	5		10-12	--	--
Abaca	56-63	--	12-13	1	5-10	--	--
Cotton	85-90	5.7		0-1	7.85-8.5	0.6	--
Coir	32-43	0.15-0.25	40-45	3-4	8		30-49

2.2 KENAF FIBER REINFORCED COMPOSITE

During early 80's researches focused on the possibility replacement of heavy metals so that materials having high density can be replaced with the low density and high strength materials. Thus the usage of polymers in various applications grow exponentially. Now-a-days, the application of polymer based components has widened enormously from house hold utilities to space applications. It is the known fact that the usage of polymers cannot be replaced all of a sudden but can be decreased to some percentage to reduce the disposal problem. In the same way, the synthetic fibers especially glass fiber possess enormous threat to the environment and to the health of the workers who are involved in the production of the same. In order to replace them, currently researches focus on the natural fibers and their feasibility as the reinforcement in the polymer matrix. Natural fibers, an environmental friendly, low cost, available in abundance and good weight – strength property made them as a suitable alternate to glass fiber (Ishak et al 2010). Natural fibers are extracted from various parts of the plant (stem, leaf and bark) and classified accordingly. The most widely used plant fibers include sisal, banana, kenaf, coir etc.

Kenaf (Hibiscus Cannabinus L) belongs to the family of hibiscus, a biodegradable and environmental friendly crop. Kenaf is grown in the tropical and subtropical regions (Villar et al 2009). Hence most of the researches in kenaf fibers are carried out by the researchers in those areas. Kenaf fiber has been successfully reinforced with both thermo plastic and thermoset resin. This indicates the feasibility and a new reinforcing material for polymer matrix composite**.** Ahmad et al 2010 reviewed several empirical studies and highlighted the use of kenaf for pulp production (beating, fractionation, and recycled fiber).

Tao et al 1999 investigated the spinning and weaving of yarns from finer and softer kenaf fiber bundles treated with modified Degumming method. The result showed that blends are stiffer and less recoverable after deformation than the 100% cotton fabric. The kenaf/cotton blended fabric has potential applications of outerwear apparel, which should greatly increase new uses for kenaf fibers and add value to the crop.

Feng et al 2001 reported the structure-property relationships of kenaf fiber reinforced polypropylene (PP) and its impact copolymers

Maleated polypropylenes (MAPP) used effectively to improve the compatibility between the fiber and matrix. The effect of coupling agent on the mechanical properties and dynamic mechanical behavior is reported. Results also indicated that the impact copolymer blends with coupling agent have better high temperature moduli and lower creep compliance than the uncoupled systems. The crystallization and melting behavior of kenaf composites were compared using differential scanning calorimeter.

Nishino et al 2003 investigated the mechanical properties of kenaf fiber reinforced poly-l-lactic acid (PLLA) resin composites. This study showed that the tensile strength and modulus were higher than those of the kenaf fiber and the PLLA film themselves. Young's modulus and the tensile strength of the kenaf/PLLA composite having the fiber content of 70 vol % were comparable to those of traditional composites. It was due to the strong interaction between the kenaf fiber and PLLA.

Tajvidi et al 2005 investigated the applicability of TTS (Time Temperature Superposition) to the prediction of creep behavior of a kenaf fiber/HDPE composite and compared TTS master curve with actual creep test data and also evaluated the use of horizontal and vertical shifting and two dimensional minimization methods to obtain master curves covering higher range of frequencies than that evaluated empirically.

Chen et al 2005 compared the two types of experimental kenaf/ramie nonwovens with different binders, in terms of mechanical properties, thermal mechanical property, and thermal conductivity. The study revealed that the padding times significantly influenced the tensile properties of the acrylic-copolymer bonded composite.

Mwaikambo 2006 described the historical use of plant fibers, methods of extraction and/or separation, physical and mechanical properties and discussed future uses for these fibers. Plant fibers are an alternative resource to synthetic fibers as reinforcement for polymeric materials for the manufacture of cheap, renewable and environmentally friendly composites.

Clemons and Sanadi 2007 investigated the effects of fiber content, coupling agent and temperature on the impact performance of fiber –plastic composites. They observed energy to maximum load (EML) values for kenaf composites were about half of those for unfilled PP specimens in reversed notch tests at room temperature, but performance was similar at low temperatures. This investigation proved that Izod impact test can increase the information gained on the impact performance of composites made from polypropylene (PP) reinforced with kenaf fiber. Rather than yielding a single energy value, the results show the shape of the load-deflection curve, which leads to greater insight into the behavior of the material.

Zampaloni et al 2007 used kenaf–maleated polypropylene reinforced composites. They have concluded that fiber content of 30 % and 40 % by weight has been proven to provide adequate reinforcement and to increase the strength of the composite. Compression molding method was used to fabricate the composite sheets. The kenaf/PP sheet showed consistent formability even though each sheet was fabricated by hand. It was found that the temperature of both the die and the preform must be elevated in order to prevent cooling and tearing during forming.

Liu et al 2007 fabricated kenaf fiber reinforced composites by injection and compression molding methods. The fiber length also varied to examine the effect of fiber size. Composites characterized with storage modulus, HDT, impact strength and surface morphology. The influences of processing methods and fiber length on natural fiber reinforced soy based bio composites were determined. It was observed that fractured fiber length on the impact fracture surface increases with increasing the fiber length and fiber content.

Ochi 2008 investigated the mechanical properties of kenaf fiber reinforced poly lactic acid composite. Their study showed that the flexural properties of composite increased with increase in the fiber content. Also, the biodegradable study showed that 38 % of weight reduces in four weeks of compositing. Biodegradability of the composites was confirmed experimentally.

Anuar et al 2008 discussed on optimum processing parameters of Thermo plastic natural rubber (TPNR) hybrid composites with kenaf and glass fiber. The effect of fiber loading and fiber volume fraction were also studied. The result of tensile strength showed that increasing kenaf fiber content substantially reduced the tensile strength and modulus. The effect of fiber loading (0, 10, 15, and 20 % by volume) and different fiber volume fractions (KF:GF ratios equal to 100 : 0, 70 : 30, 50 : 50, 30 : 70, and 0 : 100) were also studied. The effects of coupling agents, silane, and MAPP on tensile properties were also investigated.

Lee et al 2009 evaluated the effect of kenaf bast fiber orientation and formulation on the properties of laminates, and characterized the thermal and interfacial properties at the kenaf fiber and polymer interface. The fractographs indicated a weak interaction between the kenaf fiber surface and polypropylene (PP) matrix. Fibers from middle section of the kenaf stem showed relatively smoother surfaces and higher strength compared to those from other sections.

Nosbi et al 2011 studied the behaviors of kenaf fibers after long term immersion in water. The tensile strength of the immersed kenaf fibers decreased with increasing immersion time. They attempted to evaluate the effect of several water conditions on the tensile properties of kenaf fiber. Result showed that water absorption pattern of the kenaf fiber immersed in sea water showed highest absorption characteristics compared to distilled water and acidic solution.

Narish et al 2010 investigated the possibilities of using kenaf fiber as reinforcement for polyurethane composites meant for bearing applications. The experiments were conducted on a block-on-disc (BOD) machine with a polished stainless-steel counter face at various applied loads (30 – 60 N) and fiber orientations. Adhesive wear results revealed that thermoplastic treated kenaf fiber-reinforced polyurethane (T-KFRP) (in AP-O) has a high degree of wear resistance compared to neat polyurethane (N-PU). SEM observations showed different wear mechanisms such as fiber detachment, pitting, delamination, and micro-cracks

Akil et al 2011 reviewed the characteristics of kenaf fiber reinforced composites in terms of mechanical properties, thermal properties ,as well as water absorption properties. Moreover, the manufacturing process and their technical issues were also addressed. They have studied developments made in the area of kenaf fiber reinforced composites. It was found that the use of kenaf fibers can generate jobs in both rural and urban areas.

Ahmad et al 2011 studied the influence of alkali treatment of kenaf fibers and addition of LNR (Liquid Natural Rubber) in polyester matrix on the mechanical properties of composites. Alkali treated fibers were found to provide better impact and flexural strengths to the composites. Measurement of environmental stress cracking resistance (ESCR) shows that the composite with acid medium has the fastest diffusion rate, followed by that with base medium, and then without medium. Alkalization of kenaf shows good properties on impact, flexural, and fracture toughness compared to untreated kenaf composite.

Taib et al 2008 fabricated bio composites from kenaf bast fiber and PLA and studied tensile properties and water absorption behavior of bio composites from kenaf bast fiber and PLA. They have attempted to develop thermo formable non woven blend fabrics containing chemically retted kenaf for automotive applications.

Karnani et al 1997 studied the influence of ligno cellulosic composites by reactive extrusion processing in which good interfacial adhesion is generated by a combination of fiber modification and matrix modification methods. Typical mechanical test is reported. They discussed about the improved adhesion resulting from reactions and enhanced polar interactions at phase boundaries.

Gita et al 1999 studied the effect of frost on kenaf fiber quality. They conducted detailed evaluation on fiber processing and chemical composition. Frost-damaged kenaf with fungal growth was decorticated by hand and divided into six sections (26.88 cm each) from the base to tip of the stem and then retted chemically or bacterially in the laboratory. Fiber characteristics was also compared between two process and six locations.

Yibin et al 2009 compared the experimental and theoretical tensile properties of kenaf fiber bundle. Both experimental and theoretical results show that the tensile strength of the kenaf fiber bundle increases with increasing the strain rate whereas tensile modulus remain unchanged due to change in strain rate.

Vineta et al 2009 compared the composite prepared by injection and compression molded kenaf/pp. The study showed that the process parameters have no significant effect on the properties of composite. Jamal 2007 et al investigated the tensile properties of wood flour/kenaf–pp composite. The investigation revealed that the addition of long kenaf fiber as reinforcement with wood flour-pp composite has increased the tensile strength and modulus significantly. Symington et al 2009 studied the tensile properties of kenaf fibers for structural application. The study shows that the alkalization will increase the properties of the fiber.

Maddern and Franch 1989 studied the papermaking properties of bleached soda-AQ kenaf bark and core pulp. They found that the bark fibers are long, thin and stiff providing good tear, light scattering and moderate bonding. Ishak et al 2010 used kenaf fiber as reinforcement in bio-composite material. The objective was to compare the mechanical properties of short kenaf bast and core fiber reinforced unsaturated polyester composites with varying fiber weight fraction i.e. 0 %, 5 %, 10 %, 20 %, 30 % and 40 %. The results also showed that the optimum fiber content for achieving highest tensile strength for both bast and core fibre composites were 20 %wt.

Bhardwaj et al 2007 studied the influence of refining on physical and electro-kinetic properties of various cellulosic fibers and found that beating increases the surface charge, specific surface area and specific volume of fibers, but did not change the total fiber content.

2.3 CHEMICAL TREATMENT OF NATURAL FIBER REINFORCED COMPOSITE

Mohd Yuhazri et al 2011 investigated the effect of NaOH on kenaf fiber reinforced polyester composite. It shows that the mechanical properties of the composite increases with increasing the concentration of the alkali.

Mohamed Edeerozey et al 2007, Sharifah et al 2004 study shows that the kenaf fiber can be reinforced with both thermoplastic and thermoset plastic. However, the increase in the property will be achieved by surface modification of the fiber. Vineta et al 2009 studied the compression and injection molding of polypropylene (PP) and polylactic acid (PLA) based composites reinforced with rice husk or kenaf fibers and their basic properties were examined. It was found that the techniques applied for manufacturing of the eco-composites under certain processing conditions did not induce significant changes in the mechanical properties. The experimental results suggested that the compression and injection molding are suitable for processing of eco-composites. Roger et al 2000 discussed the factors affecting the agrofibers and found that the chemical composition and physical properties of them depends on part from which fiber is extracted; the age of plant and the extraction methods.

Mehdi Jonoobi et al 2009 characterized the kenaf (Hibiscus cannabinus) nano fibers by environmental scanning electron microscopy (ESEM) and transmission electron microscopy (TEM), were isolated from unbleached and bleached pulp by a combination of chemical and mechanical treatments. Moreover, thermogravimetric analysis (TGA) indicated that both pulp types as well as the nanofibers displayed a superior thermal stability as compared to the raw kenaf. Fourier transform infrared (FTIR) spectroscopy demonstrated that lignin and hemi cellulose decreased in the pulping process and that lignin was almost completely removed during bleaching.

Tajvidi et al 2006 investigated the effect of modification on viscoelastic properties of kenaf fiber-reinforced PP composites. An increase in storage and loss moduli and a decrease in the mechanical loss factor were observed for all treated composites, indicating more elastic behavior of the composites when compared with the pure PP.

Aziz et al 2005 investigated the effect of modified polyester resins in alkali-treated kenaf fiber composites. Four types of polyester resins were used in this study. Traditionally, hemp has been used to make ropes but these days its fiber is used to make items such as clothing, toys and shoes. The fiber is fully biodegradable, is non-toxic and may be recycled.

Rajeev et al 1997 has compared the tensile properties of kenaf fiber treated using silane with sisal fiber. They found that the composites based on the modified matrix have, in general, superior mechanical properties to those containing the unmodified matrix.

Maya Jacob et al 2010 used zein as a coupling agent in this experimental study. Fibers are characterised by using FTIR. Chemically modified kenaf fibers were found to possess improved mechanical and visco-elastic properties.

To reduce moisture sensitivity and biological decay and to optimize properties of the fiber matrix interface, the natural fibers used in polymer composite materials can be modified by chemical and physical methods (Feng et al 2001). By treating the fibers with suitable chemicals, the reinforcing efficiency of the fibers in the composite and the interfacial adhesion between fibers and most polymers matrices was solved Mattoso et al 1997, Martins and Joekes 2003. Chemical treatment of the fiber cleaned the fiber surface, chemically modified the surface, delayed the moisture absorption process and increased the surface roughness. It has been found that the alkalization treatment improved the mechanical properties of the kenaf fiber significantly as compared to untreated kenaf fiber Mohd Edeerozey et al 2007. The following surface modification method was used to improve the sisal fiber/matrix interaction: alkali treatment, H_2SO_4 treatment, conjoint H_2SO_4 and alkali treatment, benzol/alcohol dewax treatment, acetylated treatment, thermal treatment, alkali-thermal treatment and thermal-alkali treatment Li et al 2000.

Ray and Sarkar 2001 investigated the changes occurring in jute fibers after 5 % NaOH solution treatment for different periods of 0, 2, 4, 6, and 8 hrs. A 9.63 % weight loss was measured during 2 hr of the treatment with a drop of hemicellulose content from 22 to 12.90 %. The tenacity and modulus of treated fibers improved by 45 % and 79 %, respectively, and the breaking strain was reduced by 23 % after 8 hr of the treatment. The crystallinity of the fibers increased only after 6 hr of the treatment.

Ray et al 2001 investigated the impact fatigue behavior of vinylester matrix composites reinforced with untreated and alkali treated jute fibers. Longer duration of alkali treatment increased the crystallinity and gave better fiber dispersion due to the removal of hemicellulose. The alkalization for 4hr was the optimum treatment time to improve the interfacial bonding and fiber strength. The flexural strength of alkali treated jute fiber composites was higher than that of untreated jute fiber composites. This might be caused by higher surface area of the alkali treated jute fiber to adhere polymer matrix.

Ray et al 2001 treated jute fiber with 5 % NaOH for 2, 4, 6, and 8 hrs. Thermal analysis showed that the moisture desorption was observed at a lower temperature in the case of all treated fibers. The fineness of the fiber which provides more surface area might be the reason for moisture evaporation. The moisture loss of alkali treated jute fiber for 6 and 8 hrs decreased due to the increase of crystallinity of the fibers. The percent degradation of hemicelluloses decreased considerably in all the treated fibers.

Mwaikambo and Ansell 2002 studied thermal resistance, crystallinity index, and surface morphology of untreated and alkali treated natural fibers. The concentration of alkali (NaOH) solution affected thermal resistance of the fibers. A rapid degradation of cellulose was observed between 0.8 and 8 % NaOH, and beyond this range the degradation was found to be insignificant. There was insignificant drop in the crystallinity index of hemp fiber while sisal, jute, and kapok fibers exhibited a slight increase in crystallinity index at the NaOH concentration range of 0.8-30 %. SEM micrograph of all untreated fibers showed a relatively smooth surface whereas, all alkali treated fibers showed uneven surfaces due to the loss of low molecular weight species and hemicellulose.

Sydenstricker et al 2003 studied the thermal properties of alkali (NaOH) treated sisal fibers. Lignin content and density of fibers were reduced with NaOH treatment. In addition, alkali treatment caused on a significant reduction in moisture absorption of sisal fiber. TGA thermograms showed that the NaOH treated fiber became more thermally resistant than the untreated fiber.

Razera and Frollini 2004 investigated the effect of alkali (NaOH) treatment on the physical properties of jute-phenolic resin composites. Fibers were treated with a 5 % NaOH solution. The tensile strength, impact strength, and elongation at break of NaOH treated fiber composites were the highest while the water uptake was the lowest. SEM micrograph of the impact fracture surface revealed that the alkali treated fibers embedded with the matrix to a higher extent than untreated fibers. Further, the pull-out mechanism could be observed in the case of untreated jute fiber. The improvement of adhesion between jute fibers and phenolic resin caused by the NaOH treatment which contributed to the reaction of hydroxymethyl and hydroxyl groups of phenolic resin and jute fibers, respectively.

2.4 CHEMICAL TREATMENT OF WOVEN FIBER COMPOSITE

Srinivasababu et al 2009 introduced okra for the first time preparation of okra fiber reinforced polyester composites. Chemically treated (chemical treatment-2) okra woven FRP composites showed the highest tensile strength and modulus of 64.41 MPa and 946.44 MPa respectively than all other untreated and treated okra FRP composites is 34.31 % and 39.84 % higher than pure polyester specimen Jannah et al 2011, and Jawaid et al 2011, Studied chemical surface modification of woven composites.

Mohd Edeerozey et al 2007 carried out the chemical modification of kenaf fibers. Different concentrations of NaOH were used and SEM was carried out to understand the morphological changes. They observed that treated kenaf fibers exhibited relatively better mechanical properties than untreated fibers. In addition, the optimum concentration of NaOH was found to be 6 %. A decrease in impurities was observed in the case of treated fibers. Fiber bundle tests were also performed and the strength of 6 % NaOH-treated fiber bundles was found to be higher by 13%. Ochi 2008 studied biodegradability of kenaf/PLA composites was examined for four weeks using a garbage processing machine. Experimental results showed that the weight of composites decreased 38% after four weeks of composting. Moreover, tensile and flexural strength and elastic moduli of the kenaf fiber-reinforced composites increased linearly up to a fiber content of 50%.

Aziz et al 2005 discussed the effect of alkalization on fiber alignment. Maldas et al 1995 investigated the influence of chemical treatment. Nishino et al 2006 investigated the influence of silane coupling agent on kenaf fiber-reinforced PLA. The stress on the fibers in the composite under transverse load was monitored in situ and non destructive methods using X-ray diffraction. Pothan et al 2006 investigated the influence of chemical modification on dynamic mechanical properties of banana fiber-reinforced polyester composites. A number of silane coupling agents were used to modify the banana fibers. The damping peaks were found to be dependent on the nature of chemical treatment.

Rozli Zulkifli et al 2009 studied the effect of chemical treatment on the interlaminar fracture toughness of woven silk composite. The results give the indi- cation of the effect of the fiber surface treatment and number of layers because the thicknesses of all the specimens are the same. In order to increase the interlaminar fracture toughness of woven silk/epoxy composites, surface treatment using silane based coupling agent gives a slightly improve prop- erties and usage of multiple layers of woven silk fiber has proven to be effective. Rafah 2010 investigation reveals that the chemical treatment improved the dielectric strength and thermal conductivity by about 29.37 % and 139 % respectively compared with untreated fiber composites. Finally, the dielectric constant value of the treated fiber composite was found to be lower than the untreated fiber compos- ite and virgin unsaturated polyester.

2.5 BANANA FIBER REINFORCED COMPOSITE

Pothan et al 1997 compared the mechanical properties of banana fiber reinforced polyester with jute, sisal and coir reinforced composites. Water absorption showed an increase in water uptake with increase in fiber content. Maximum tensile strength was observed at 30 mm fiber length while a maximum impact strength was observed for 40 mm fiber length. Comparative analysis with other natural fibers shows banana fiber composite has superior mechanical properties than other composites.

Sapuan et al 2007 described the fabrication of a multipurpose table using banana trunk fiber-woven fabric-reinforced composite material. Barreto et al 2010 studied the effect of NaOH treatment on structure, dielectric and biodegradability of banana fiber. The study showed that NaOH increased the crystalline fraction of the banana fiber, due to the partial removal of the lignin. Sunil et al 2010 studied the effect of Maleic Anhydride (MA) and glycerol triacetate ester on the properties of the banana/PLA composite bio-composites. The thermal stability of the bio-composites was evaluated using

TGA, DSC, DMA and HDT techniques. Scanning Electron Microscopy revealed the surface morphology of the impact fractured bio-composites. The morphological investigations using Scanning electron microscopy (SEM) indicated improved interfacial adhesion due to chemical treatment of fibers.

Merlini et al 2011 investigated the effect of alkali treatment on the banana fiber and its polyurethane reinforced composite. The study included the treatment of banana fibers with 10 % wt of NaOH, prediction of critical fiber length, tensile strength of the fiber and composite. The study shows that alkali treatment improves the interfacial adhesion between fiber and matrix which in turn increases the tensile strength of the composite.

Deepa et al 2011 extruded the nano-fibers from banana fiber using steam explosion technique. Chemical analysis was carried out to investigate the presence of cellulose, lignin and hollow cellulose content of nano-fiber. The cellulose percentage of banana fiber increased from 63 % to 95 % which is very high when compared with conventional method of extraction of nano-fibres. Also, the investigation revealed that the thermal stability of the treated nano-fibers is higher than that of untreated fiber.

Chattopadhyay et al 2011 analyzed the biodegradability of banana, bamboo, and pineapple leaf fiber reinforced with polypropylene to form composites. The study showed that the biodegradability of the entire composite is between 5-15 %.Hence, natural fibers from renewable resources which act as reinforcing agent in various synthetic polymers can address to the management of waste plastics, by reducing the amount of polymer content used which in turn, will reduce the generation of waste of the non biodegradable polymers.

Shih and Huang 2011 prepared the banana fiber reinforced Poly Lactic Acid using melt blend technique. Composite prepared using coupling agent and chemical modification exhibited improved composite properties because of improved compatibility between fiber and resin.

Jandas et al 2011 studied the influence of fiber surface treatments on the banana/PLA. The properties of bio composites were evaluated using mechanical tests, DSC and TGA and visco-elastic measurements by DMA. Visco-elastic measurements using DMA confirmed an increase in storage modulus and lower the damping values in the silane treated bio-composites.

Singh et al 2012 investigated the influence of silica powder on tensile properties of banana fiber/epoxy composite. It showed that the addition of silica increases the modulus of elasticity and impact strength of composite.

Khalil et al 2006 studied fine structure of plant fibers like Banana and pineapple fibers using SEM .The chemical composition of fiber was analyzed according to TAPPI method. Above studies helpful in reducing environmental and health hazards associated with disposal of plant waste. Pothan et al 2003 studied influence of banana fiber on the viscoelastic properties of polyester. The effect of fiber content, frequency and temperature on the viscoelastic properties is reported. The elevation of Tg is taken as a measure of the interfacial interaction and the effect of fiber content on the Tg values is reported.

2.6 HYBRID COMPOSITES

Hybridization of fibers in single matrix provides another dimension to the potential versatility of fiber reinforced composite materials (Marom et al 1978). In the case of fiber reinforced polymer composites, the hybrid refers to the use of various combinations of fiber and particulate in polymer matrices. It can be used to meet the diverse and competing design requirements in a more cost effective way than conventional composites. In the case of the natural fiber reinforced polymer composites, though they are attractive, they have some limitations such as lower strength, lower modulus, and relatively poor moisture resistance, when compared to man-made fiber reinforced polymer composites. So, the material engineers have found out a solution to overcome these limitations viz., effective hybridization of natural fibers with man-made fiber, for instance, glass fiber. By using hybrid composite that contains two or more types of different fibers, it is possible to exploit the properties of such fibers. Few natural–glass fiber polymers composites, bamboo-glass fiber reinforced polymer matrix hybrid composite (Moe and Kin 2000), short hemp fiber/glass fiber-reinforced polypropylene hybrid composites (Suhara and Mohini 2007), sisal fiber-glass fiber hybrid unsaturated polyester composites (John and Venkata 2004) were prepared and their properties were also determined.

But, in recent years, increasing emphasis is given for eco-conservation and reduction of pollution. With these aims, all materials engineers, scientists and industrialists are now trying to fully replace the man-made fibers like glass fibers by fully natural fibers for polymer matrices. Venkata et al 2008 studied the mechanical properties of the natural fiber reinforced composites based on kapok/sisal and its hybrid composites with polyester as resin matrix. Hardness and flexural properties of kapok/sisal composites were determined . The maximum strength was observed for the optimum fabric loadings. The effect of alkali treatment of fabrics on the properties of composites was also studied. Increasing the sisal fiber content resulted in a reduction in the hardness and flexural properties. The properties were found to increase when alkali treated fabrics were used for reinforcing the composite. The addition of a relatively small amount of sisal fiber to kapok reinforced polyester matrix enhanced the compressive strength of the resulting hybrid composites. A significant improvement in compressive strength of these hybrid composites were observed after NaOH treatment. The chemical resistance of these hybrid composites to different chemical reagents and water has been studied.

Maya Jacob et al 2004 investigated sisal/oil palm hybrid fiber reinforced rubber composites based on the concentration and modification of fiber surface. The results showed that increasing the concentration of fibers resulted in the reduction of tensile strength and tear strength, but increased modulus of the composites. Idicula et al 2005 studied the static and dynamic mechanical properties of randomly oriented short banana/sisal hybrid fiber reinforced polyester composites. Composites were prepared by varying the relative volume fraction of the two fibers at each fiber loading. When the fiber loading was increased, tensile, flexural, and impact properties improved. Enhanced performance was shown by composites having volume fraction of 40 %. Tensile strength, tensile modulus, flexural strength, and flexural modulus showed a positive hybrid effect when the volume ratio of the fiber was varied in the hybrid composites at each fiber loading. Maximum tensile strength was observed in composites having volume ratio of banana and sisal 3:1. When the volume ratio of sisal increased, the impact strength of the composite increased. Different layering patterns were tried at volume fraction of 40 %, keeping the volume ratio of fibers 1:1. Tensile properties were slightly greater in the trilayer composite with banana as the skin material. Bilayer composites showed higher flexural and impact property. SEM studies were carried out to evaluate fiber/matrix interactions. Experimental results were compared with theoretical predictions.

Junior et al 2004 studied the tensile strength of ramie–cotton fabrics hybrid polyester composites as a function of the volume fraction and orientation of the ramie fibers. Composites were tensile tested with ramie fibers oriented parallel, (0), to the tensile axis and with various stacking sequence configurations (0/90). The results obtained showed that the main parameter governing the tensile properties of the composites was the ramie volume fraction parallel to the direction of the tensile axis. The contribution of the cotton fibers was shown to be minimal. The results obtained for the tensile strength of the composites were shown to follow a common rule of mixtures law, disregarding the contribution of the cotton fibers. Tensile strength increased up to 38 % in comparison to the matrix. Main parameter governing the tensile properties of the composites was the ramie volume fraction. Alsina et al 2005 and Biswal et al 2011 studied the thermal diffusivity, thermal conductivity and specific heat of jute/cotton, sisal/cotton and ramie/cotton hybrid fabric-reinforced with unsaturated polyester composite.

Reis et al 2007 studied the static and fatigue flexural behaviour of hybrid laminated composites fabricated with a hemp natural fiber /PP core and glass fiber/PP surface layers at each side of the specimen. They proved that failure mechanism in hybrid laminated composites are strongly influenced by high gradients of shear and normal stress near the interface between core and skin .

Manikandan and Velmurugan 2007 fabricated palmyra/glass fiber reinforced composite with rooflite resin as matrix. They found that mechanical properties of composites increased due to addition of glass fiber with palmyra fiber in the matrix. They concluded that the addition of glass fiber with palmyra fiber in the matrix decreases the moisture absorption of the composites.

Idicula et al 2010 studied the mechanical performance of banana/sisal reinforced polyester composites. Tensile properties of both fibers were determined. Tensile properties of the composites as a function of fiber concentration and fiber composition and layering patterns were determined.

2.7 WOVEN HYBRID COMPOSITES

Woven fabric composites, in particular, are constructed by weaving two fiber tows into each other to form a layer. These layers are then impregnated with a resin or matrix material, stacked in a desired orientation, and cured to obtain a composite laminate. The interlacing of fiber bundles has several advantages such as increasing the strength of the lamina, greater damage tolerance, as well as providing a possibility to produce near net shape structural components.

Agricultural or biodegradable material plays important role in human life. The advantage of using such resource is that they are widely distributed all over the world, its multifunctional, strength and biodegradable (Rowell et al 2000 and Nosbi 1999). Natural fibers are used in different forms such as reinforced composites such as continuous, randomly oriented and woven fabric for reinforcing composites. Further, there is growing interest in the use of natural fiber composites for structural and automotive applications (Bledgki 1999 and Satyanarayana et al 1983). In the case of aircraft structures, woven or braided composites are used for a wide variety of cross-sectional forms such as stiffeners, truss members, rotor blade, spars, etc. to reduce the fabrication costs (Chen et al 2005). Various processes such as weaving, braiding or knitting, etc form reinforcement of these composites.

Such capabilities are very important for producing thick laminates. However, these advantages come at the expense of some loss in the in-plane stiffness and strength, which depends upon the weave architecture (Li et al 2001 and 2009). There is certainly a need for sound engineering data as well as efficient analytical/design methodologies to evaluate different parameters. These design methodologies must account for processing parameters and micro structural/geometrical features for accurate modeling of such composites. There are several geometries/architectures for woven composites. In the case of two-dimensional woven fabric composites, two sets of mutually orthogonal sets of yarns of the same material (non-hybrid) or different material (hybrid) are interlaced with each other.

The various types of architectures can be formed depending on how the pattern in the interlaced regions is repeated. Plain weave is a special case of two-dimensional woven fabric composites. In the case of plain woven composites, a “warp” or longitudinal fiber tow are interlaced with every second “fill” or with fiber tow. A woven fabric contains fibers oriented on at least two axes, in order to provide great strength and stiffness (Rajiv et al 1995).

Sapuan and Maleque 2004 studied the use of woven banana fiber reinforced composites for the development of household furniture. They have designed and fabricated banana woven fabric reinforcement epoxy for household telephone stand. Chen et al. 2005 investigated the process ability of natural fibers in making an uniform sandwich composites and evaluated the end use performance in terms of mechanical properties ,wet properties and thermal properties .The DMA result showed that uniform composite feature a higher softening temperature (140° C)and melting temperature (160° C) , in contrast to the sandwich composites with softening point(120° C) and melting point 140 $^{\circ}$ C concluded, that selection of bonding fibers would be critically important for manufacturing high performance automotive components.

Ahmed et al 2007 evaluated the elastic properties and notch sensitivity of jute and jute-glass fiber reinforced polyester hybrid composites. They investigated notch sensitivity using point stress criterion and modified point stress criterion. The young’s modulus in warp and weft direction increases whereas the Poisson’s ratio decreases with the increases in fiber content. Modified PSC model has resulted in excellent agreement between the experimental and predicted values. They discussed hybridization of glass fiber with jute fiber as well the effect of hole size on the notch sensitivity. It was observed that the empirical relations and correlations developed for the predictions of notch sensitivity of synthetic fiber composite also hold good for jute and jute glass hybrid composites.

Sabeel Ahmed et al 2008 studied the effect of hybridization and stacking sequence on tensile, flexural and interlaminar shear properties of untreated woven jute and glass fabric reinforced polyester hybrid composites. Ariel Stocchi et al 2006 studied the alkali treatment superimposed to biaxial tensile stress of woven jute fabric/vinylester laminates. Adekunle et al 2012 studied impact and flexural properties of Flax fabrics and Lyocell fiber reinforced composites. They have studied water absorption properties of the composites and it was noted that the hybridization with Lyocell fiber reduced the water uptake.

Pothan et al 2008 studied the effect of weave architecture ,resin viscosity, chemical modification, and injection pressure on the permeability of sisal fabric and the ultimate mechanical properties of woven sisal fiber reinforced polyester composites prepared by RTM Technique. Composites where maximum fibers are in the loading direction, combined with lower interface points, were found to give highest properties. The strength properties seem to be much higher in the case of woven reinforcement with a relatively lower fiber volume fraction in comparison to short fiber composites.

Ude et al 2010 carried out impact tests on woven natural silk/epoxy reinforced and sandwiched composite plate specimens. A low velocity instrumented falling weight impact test method was employed to determine load-deflection, load-time and absorbed energy-time behavior for evaluating the impact performance in terms of load bearing capacity, energy absorption and failure modes for phenomenological classification and analytical comparisons. They concluded that that WNS/Epoxy/Core mat displays better load bearing capacity qualities compared to the other three samples.

2.8 WEAR BEHAVIOR OF POLYMER COMPOSITE

Khedkar et al 2002 studied the wear behavior and dominant mechanisms involved during the sliding wear of PTFE composites.

DSC analysis was also performed to study the relative heat absorbing capacity and thermal stability of the various composites in an effort to correlate these properties to the tribological performance. It is proposed that the increase in the coefficient of friction could be due to the abrasive nature of carbon particles which when present at the sliding interface cause three-body abrasion.

Srinivasan et al 2007 analyzed the abrasive wear behavior of polymer matrix composites and concluded that wear mechanism map can be used for the selection of optimum working conditions. Wear test was carried out for FRP using a pin-on roller wear tester. It was observed that fracture phenomena like ironing, plastic ploughing, brittle fracture and micro cutting occurred during wear.

Mohan et al 2010 investigated the effect of silicon carbide (SiC) particulate fillers incorporation on two-body abrasive wear behavior of Glass Fabric - Epoxy (GE) composites. They correlated the two-body dry abrasive wear of unfilled glass epoxy (GE) composite and 6 wt. % SiC particulate filler loaded GE composite. The wear loss of the composites was found to increase with the increase in abrading distances. The SiC filled composite exhibited the higher wear resistance under different abrading distances. This behavior can be attributed to the presence of SiC particles on the counter surface, which act as a transfer layer and effective barriers to prevent large-scale fragmentation of epoxy. They concluded that SiC filled composite showed excellent abrasion resistance.

Tayeb and Yousif 2007 analyzed the multi-pass two-body abrasive (m-2BA) wear behaviour of CGRP composite when abraded against waterproof silicon carbide (SiC) abrasive paper of three different grades (i.e. 400, 1000, and 1500).It was found due to the attrition of the abrasive particles. Hence, wear rates are experimentally determined under dry condition for different loads (5–25 N) and rotational speeds (50 and 100 rpm), and the resulting worn surfaces were microscopically examined and categorized. Marusic et al 2008 examined the tribological properties and damages of fiber reinforced polyester laminates depending on the number of reinforcing layers, their layout and thickness. They established relationship between tribological and mechanical properties . Mechanical properties are influenced by diverse factors, not only by the type and the content of reinforcement, but also by conditions prevailing on the interface between reinforcement and the matrix.

Kranthi et al 2010 evaluated the wear behavior of a new class of epoxy based composites filled with pine wood dust. An artificial neural networks (ANN) approach was used to predict the wear behavior on various control factors. Yusoff et al 2007 conducted dry sliding wear tests on hybrid composite reinforced with natural carbon based particles such as palm shell activated carbon (PSAC) and slag. They used analysis of variance (ANOVA) for the contribution of synergic factors such as applied load, sliding distance and reinforcement content (wt. %).

Biswas and Satapathy 2009 analyzed the effect of red mud filled composites using taguchi method. It was found that filler content eroded temperature impingement angle and velocity affected the wear behavior of polymer composite. Patnaik et al 2010 reviewed various models to analyze the erosion characteristics of fiber and particulate filled polymer composites. Rout et al 2012 predicted that impact velocity is the most significant factor that affects the wear rate.

After conducting through literature review it is obvious that only a few researches have carried out using kenaf fiber as reinforcement in polyester resin. Further, it is clear that no literature is available on banana/ kenaf hybrid composite. Hence the research on woven banana/ kenaf hybrid composite was chosen as the topic for the Ph.D thesis.