

# ***Cyperus pangorei*- A Natural Fibre for Biocomposites**

*By*

**Amutha, P  
(13PTF001)**

A Thesis submitted to the  
**Avinashilingam Institute for Home Science and Higher Education for Women  
Coimbatore - 641 043**

In Partial Fulfillment of the Requirements for the  
**Degree of Master of Science**  
in  
**Textiles and Fashion Apparel**

**March, 2015**

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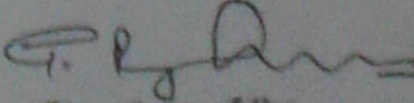
Textiles and Fashion Apparel

March, 2015

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Guide

## ACKNOWLEDGEMENT

The investigator thanks **GOD ALMIGHTY** for giving strength, courage and ability to successfully complete this research study.

The investigator fondly remembers **Late AyyaAvi. Dr. T.S. Avinashilingam, Founder President – First Chancellor** and **Late AmmaAvi. Dr. (Mrs.) RajammaP. Devadas, Former Chancellor**, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore.

The investigator records her sincere thanks to **Dr. (Thiru).T.S.K. Meenakshisundaram, M.A., M.Phil., Ph.D.** Chancellor, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for providing the infrastructural facilities for the conduct of the study.

The investigator wishes to express her profound gratitude to **Hon. Col. Dr. (Mrs.) Sheela Ramachandran, M.Sc., P.G. Dip., Ph.D.**, Vice -Chancellor, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for being a constant source of inspiration, motivation and guidance during the course of the study.

The investigator extends her sincere thanks to **Dr. (Mrs.) A. Venmathi, M.Sc., Dip. Ed., M.Phil., Ph.D.**, Registrar(i/c), Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for extending all possible help for the smooth conduct of the study.

The investigator wishes to acknowledge heartfelt thanks to her beloved Director, Halls of Residence, **Dr. (Mrs.) Saroja Prabhakaran, M.A., Dip. Ed., Ph.D.**, Avinashilingam Institute for Home Science and Higher her constant encouragement and support for the successful completion of the study.

She expresses her respectful regards and sincere thanks to **Dr. (Mrs.) N.Vasugi Raaja, M.Sc., MBA., M.Phil., Ph.D.**, Dean, Faculty of Home Science and Professor and Head of the Department of Textiles and Clothing, Avinashilingam Institute for Home Science and Higher Education for Women,

Coimbatore, for rendering all helps needed for the successful completion of the study.

The investigator feels extremely privileged to have worked under the able guidance of her esteemed guide **Dr. G. Bagyalakshmi M.Sc., M.Phil., Ph.D** Assistant Professor (SS), Department of Textiles and Clothing, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for her patience, effective guidance, untiring enthusiasm, meticulous efforts, abiding interest, useful suggestions, innovative ideas and motivation for the successful execution of the study.

The investigator expresses her thanks to all the **members of staff** in the Department of Textiles and Clothing for their help to complete this study.

She is thankful to Avinashilingam Institute for Home Science and Higher Education for Women, University, Coimbatore, **South Indian Textile Research Association (SITRA), CIPET, and Kalasalingam University, Madurai, for providing tests laboratory and library facilities.**

The investigator owes her sincere thanks and gratitude to her beloved **parents** for their constant encouragement, blessings, help, care and support rendered for the successful completion of the study. Finally, the investigator expresses thanks to her **friends** who extended their co-operation and support to finish this study.

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# 1. INTRODUCTION

The increasing pollution caused by the use of plastics and emissions during incineration is affecting the food we eat, water we drink, air we breathe and threatening the greatest right of human beings, the right to live. Keeping up with the developments in technology, it is compulsory that all the developing materials are not environmentally hazardous. The persistence of plastics in the environment, shortage of landfill space, concerns over emissions resulting from incineration, and hazards to human health as well as hazards to animals, birds and fish from entrapment or ingestion of these materials have spurred the efforts to find more environment friendly alternative materials (Kumar *et al.*, 2011).

Therefore the use of renewable bio-based plant and agricultural products are the need of the hour. In addition bio-plastics must have the same desirable properties as obtained in conventional plastics. The most important factors to the formation of a successful biodegradable polymer industry include cost reduction as well as public and political acceptance (Mohanty *et al.*, 2000).

A Composite is defined as a material having two or more distinct materials differing in form or composition on a micro scale. The continuous phase of the composite is termed as matrix while the other components are referred to as reinforcement or as fillers. Ideally the fillers added to the matrix will act as both reinforcement and filler. Composites are classified into three main categories. They are fibre reinforced composites, particle reinforced composites and structural composites (laminates and sandwich panels) (Nagarajan *et al.*, 2011).

Polymers are the most widely used matrix materials. Compared to metals and ceramics, the mechanical properties of polymers, especially their strength and stiffness are seen as inadequate. But this drawback in polymers can be overcome by reinforcement with other materials. Processing conditions and equipment for manufacturing polymer matrix composites are simpler. Such materials often result in light weight structures with high stiffness. The properties of these materials can be tailored for specific applications thereby reducing energy needs and saving weight.

Most of today's synthetic polymers are produced from petrochemicals and are not biodegradable (Cheung, 2009). Following an exceptional period of growth (Fontana, 2004) in the use of glass fibre reinforced synthetic resin matrices during the past 80 years, and recently advanced polymer composites containing carbon and glass fibres have been utilized extensively in the aerospace, automotive, and construction industries (Lee *et al.*, 2009). Since the matrices and the fibre reinforcements in these advanced composites are based on mineral resources that have been long term sustainability but accumulating environmental pollution. While recycling may be a viable strategy, the complicated mixed morphology of composite materials makes them inherently difficult to recycle.

According to the study, about 25% reduction in the weight of the vehicle is equivalent to a savings of 250 million barrels of crude oil and reduction in Co<sub>2</sub> emissions to the tune of 220 billion pounds per annum (Srikanth, 2011). Hence decreasing dependence on fossil resources in energy and transport sectors are the main goals. To achieve this, different routes such as alternative power, reduction of fuel consumption by wider introduction of lightweight structures from conventional polymer composites based on synthetic polymers and glass fibres, carbon fibres and development of even lighter materials from renewable resources (bio-based composites) should be taken into consideration. The concept of bio-based materials has now become key importance due to the need to preserve our environment (John and Thomas, 2008). The development of renewably sourced composites for structural applications has been going on for quite some time using natural fibres and closed mold techniques (Goutianos *et al.*, 2006). Product made from natural fibre reinforced biodegradable polymer composites are yet to be seen in high magnitude.

The latest developments and trends in the automobile industry, including government regulations requiring increases in fuel economy and the need to reduce component costs and minimize overall vehicle weight and hence the worldwide automotive industry demand for natural fibres as an alternative material and is expected to grow (Asokan, 2012). As a result of increasing demand for environmentally friendly materials over the last few years, a number of researchers have been involved in investigating the exploitation of natural fibres as a load bearing constituents in composite materials in many areas and particularly the

automotive industry for door panels, seat backs, headliners, package trays, dashboards, trunk liners and interior parts (Njuguna *et al.*, 2011). The insertion of natural fibres not only in the automotive market sector and also in the industrial, building, and commercial market sectors has experienced a growth rate of 13% compounded over the last 10 years to an annual use of approximately 275 million kilograms (Houston, 2006). Applications of biodegradable polymers in natural fibre reinforced composites will broaden their uses.

Fibres from natural resources have been used for thousands of years for producing textiles and related products (Rottan, 2007). Cellulose is the main component of natural fibres, although the amount of pure cellulose, hemicellulose, pectin, lignin, and other extractives will vary from fibre to fibre (Bismark *et al.*, 2002). Natural fibres are subdivided based on their origins such as plants, animals or minerals. All plant fibres are composed of cellulose while animal fibres consist of proteins (hair, silk, wool). Plant fibres include Bast fibres, leaf or hard fibres, seed, fruit, wood, cereal straw and other grass fibres. The use of such materials in composites has increased due to their relative cheapness, and many other environmental benefits. Although there are number of plant fibres in nature, only few are suited for automotive application.

Lightweight, strong and low cost bio-fibres are poised to replace glass and mineral fillers in numerous interior parts. For centuries they have been made into baskets, clothing, sacks, ropes and rugs. Now plant derived bio-fibres such as jute, kenaf, hemp, flax, banana, sisal and also wood fibre are making their way into the components of cars (Bledzki, 2006). These natural fibres can compete in the markets currently dominated by petroleum based products. The production of 100% bio-based materials as substitute for petroleum based products is not an economical solution. A more viable solution would be to combine petroleum and bio-based resources to develop a cost effective product having immense applications.

Biopolymers may be renewable polymers and are not biodegradable polymers such as Polypropylene (PP), Polyethylene (PE) and biodegradable polymers such as Poly Lactic Acid (PLA), Poly Hydroxy Alkonate (PHA) reinforced with natural or bio-fibres (termed as Bio-composites) are a viable alternative to glass fibre composites and offer certain environmental advantages at the end of their use cycle when

composites are land filled or incinerated (Kim *et al.*, 2006). Scientists are looking at the various possibilities of combining bio-fibres with polymer matrices from non-renewable and renewable resources from composite materials to make a composite revolution a reality (Mohanty *et al.*, 2002) (Xue *et al.*, 2007).

Automotive play an important role in the transportation of people both individual and in groups as well as goods (Kamanth *et al.*, 2005). The automotive industry is interested in the new materials, because cars should be partially decomposable or recyclable by 2006 (Bledzki, 2006). Furthermore, light fibrous materials are also replacing conventional glass fibre reinforced plastics in other sectors from construction to the computer industry thereby benefiting the environment. The vital alternative to solve the problem is to use the agriculture residues and the grasses as reinforcement in the development of polymer composites.

Grass is an annual plant with bundles of elementary fibre cells bound by pectin middle lamellae and parenchyma cells separate fibre bundles from each other. *Cyperus* is one of the largest genera in cyperaceae. It is cosmopolitan in distribution with 650-700 species spread all over the world. Of these 80 species occur in India. Although many species grow as agricultural weeds, the family has considerable economic importance and provides food, fodder, fuel and medicines together with construction, weaving and perfumery materials (Simpson *et al.*, 2003). Today sedges are used throughout the tropics for basketry and mat weaving and they are cultivated for such purposes in parts of Africa and Asia. More specifically *C.articulates*, *C.corymboses*, *C.iria*, *C.malacensis* and *C.pangorei* are the major resources of mat sedges (Ravichandran *et al.*, 2005). ***C.pangorei*** provides raw material for mat making. It spreads all over the world and hence an attempt has been made to utilize “***Cyperus pangorei- A Natural Fibre for Biocomposites***” with the following objectives:

#### **OBJECTIVES:**

- To extract the natural fibre from *Cyperus pangorei* and examine its properties.
- To convert the extracted fibre into BioComposites.
- To evaluate and study the effectiveness of BioComposites for automobile industrial applications.

## 2. REVIEW OF LITERATURE

Review of literature collected for the study entitled “*Cyperus pangorei*- A Natural Fibre for Biocomposites” is discussed under the following headings,

### 2.1. *Cyperus pangorei*

2.1.1. Scientific classification

2.1.2. Cultivation

2.1.3. Properties

2.1.4. Uses

2.1.5. Cost

### 2.2. Extraction of fibre

2.2.1. Water retting

2.2.2. Dew retting or Field retting

2.2.3. Chemical retting

2.2.4. Enzymatic retting

2.2.5. Mechanical decortications

### 2.3. BioComposites

2.3.1. History

2.3.2. Types

2.3.3. Fabrication methods

2.3.4. Uses

2.3.5. Applications

2.3.6. Bio-Fibres

2.3.7. Biopolymers

2.3.8. Injection moulding

2.3.9. Recent developments

## 2.1. *Cyperus pangorei*

*Cyperus pangorei* previously known as *C. tegetum* roxb., *C. dehiscentis* Nees, *Papyrus pangorei* rottb., and *papyrus dehiscentis* (Mabberley, 2005). It is distributed all over India, Srilanka, Nepal and Burma. It was known since 2400 BC that the Egyptians used to make paper from the pith of the *C. pangorei* (Benazir, 2009). Highly stable nature and development pattern of the vascular bundle and fibrous arrangement of the cyperus Culm finds use in the mat industries in West Bengal (Calcutta), Kerala (Kilimangalam and Palghat), Tamil Nadu and Andhra Pradesh, in Tamil Nadu at various districts such as Vandavasi, Karur, Trichy, Tanjavur and villages such as Pattamadai, Veeravanallur, Kayathar, Alwarkurichi of Trinelveli district (Ravichandran, 2005).

The culms of *C. pangorei* provide material for making the world famous “silk mats”. Traditionally, the korai grass was woven using kathaazhai thread. The silk mats are superfine, extremely delicate and the most aristocratic mats in the world that is highly priced (Venkatesan, 2005).

### 2.1.1. Scientific Classification

Kingdom	: Plantae
Phylum	: Tracheophyta
Class	: Liliopsida
Family	: Cyperaceae (monocot family)
Genus	: <i>Cyperus</i> L
Botanical name	: <i>Cyperus pangorei</i>
Common name	: Korai grass
Local name	: Korai (Tamil), Jammu (Telungu), Chaape ullu (Kannada)

(Benazir *et al.*, 2010)

### 2.1.2. Cultivation

***Cyperus Pangorei Rottb.*** is a perennial erect herb, rhizome decumbent (Family: cyperaceae). It is smooth rust like sedge growing in tropics of India as a common weed in the vicinity of water, up to an elevation of 2000 meter (Kirtikar and Basu, 1991). The green grass normally grows along river banks and canals in rice fields and is considered as weed to a height of 90-120 cm with 3-7 mm thick sedge, clothed with brown scales. The stems are trigonous, smooth, green or grayish green colour.

The roots are short and light brown in colour and has 3-4 mm diameter with short stolons, 0.5-0.7 mm thick leaves reduced to 4-6 subaphyllous sheaths surrounding Culm (Benazir, 2012) and the leaves are 20 cm in length. Small, brown or green, fuzzy flowers produced from the tops of the stems. Korai grass is cut finely while it is still green. The grass is harvested in the months of September/ October and February/ March (<http://www.industreecrafts.org>). The outer part of the stem is used for weaving while the inside of the stem is removed with sharp edged knife (Misra, 2012).

### 2.1.3. Properties

The fibre cells in the stems cultivated from India on an average measures 0.65-0.8 mm long and 9.4-9.9  $\mu\text{m}$  wide. Processed stem strands obtained from mat weavers in Pattamadai (India) analyzed by the method of Doree (Benazir *et al.*, 2010). Composition of the fibre (<http://uses.plantnet-project.org>) is as follows:

**Table- I**  
**Chemical composition of fibre**

<b>Composition of Korai</b>	<b>In percent</b>
Holocellulose	82.92
Alpha-cellulose	41.79
Hemi-cellulose	41.13
Lignin	13.28
Waxes	01.73
Moisture	09.20

#### **2.1.4. Uses**

Cyperus pangorei mats are ideally suited for our climates and keep us cool in summer and warm in cooler months (Sukumaran, 2014). It is extensively used to make handbags, baskets, tablemats, yoga mats, window curtains, wall hangings and fans (Gandhi *et al.*, 2009). The korai grass tubers used in siddha medicine. It is cooling, and is ideal, even for new born babies (Karthikeyan, 2013). Its rhizomes have been used to promote hair growth, antiperspirant, and deodorant and used for treatment of skin disorder and eye diseases, stomachic, demulcent, antiemetic, useful in chronic diarrhea with mucus and blood and dysentery (Gupta, 2008). Anti-microbial and diuretic activities of the korai grass plant have been reported by several researchers (Jain *et al.*, 2013).

Cyperus pangorei and chitosan formed as a composite biosorbent is used for the removal of chromium (VI) from water (Malarvizhi *et al.*, 2010). The soaked korai has a better excellence of dye absorption when dyed with natural and chemical dyes (Gandhi *et al.*, 2009).

#### **2.1.5. Cost**

The New Express, 2014 reports that the korai grass costs around Rs.600 per bundle of 28 kg until a year back, and the cost is increased to Rs. 1,500 for 28 kgs.

### **2.2. Extraction of fibres**

Pectins, which are chemically complex-binding substances in plants, hold fibres in bundles. Non fibrous tissues such as pectin, lignin between the bundles in the outer region of the stems which can be extracted by retting processes (Zhang *et al.*, 2008). Retting is sometimes termed degumming. It is a chemical process for removing non-cellulosic material attached to fibres to release individual fibres. The function of the process is to ferment the binding material and remove it (Goswami *et al.*, 2011) involving bacteria (e.g., Bacillus, Clostridium) and Fungi (e.g., Aspergillus, Penicillium). During retting the organisms feed on the pectic substances, proteins of the protoplasm of the cells, sugars, starch, fats and waxes, tannin, mineral substances such as calcium, potassium, magnesium, iron, sulfur, phosphorous (Lewin, 2006).

Retting is a very important factor for processing of fibre and ultimately fibre quality (Nair, 2011). Other than the type of plant, age of plant, type and depth of water and activators, controlling the quality of water along with improving microorganisms used in the process are the keys to obtained quality fibre (Ahmed, 2001). The environmental factors, which influence retting, are hardness of retting water, presence of oxygen and iron in water, presence of microbiological agents in water like fungi and bacteria,  $p^H$ , temperature and light (Mishra, 2000).

Retting cannot improve the fibres but proper retting can ensure the original properties of the fibre (NIIR Board Consultants and Engineers, 2009). Retting should be done very carefully; otherwise the process will be ended up either under-retting or over- retting. Under retting produces coarser low quality fibres and over-retting results in maximum destruction of cellulose that leads to excessive thinning of fibre (Gopu, 2013).

After harvesting the stems are usually kept either in the field or under water for 2 to 3 weeks, during which the pectinous substances that bind the fibre with other plants tissues are softened. Micro-organisms liberate large quantities of organic matter and chemicals into the environment, including pectin, pentose, tannins and Polyphenols (Abrham *et al.*, 2013). A quality of fibre is largely determined by the retting condition and duration (Tahir *et al.*, 2011).

The degree of retting can be assessed by a biochemical approach by measuring the decrease in the amount of pectins or sugar analysis (Mooney *et al.*, 2001) which is a precise but rather time consuming technique. The textile industry uses industrial devices such as airflow, or Shirley analyser (Weyenberg *et al.*, 2003). A number of other methods such as Thermo Gravimetric Analysis (TGA) (Velde and Baetens, 2001) or Near Infra-Red Spectroscopy (NIR) are used (Candilo *et al.*, 2000). However there is no standardized technique that is fast, inexpensive and can be used in industry to assess the degree of retting.

The process of retting is being utilized for centuries in traditional ways for extracting the fibre. For industrial uses there are various types of retting methods practiced to separate the fibres (Chen *et al.*, 2007). For extraction of fibres different isolation procedures are possible, e.g. using bacteria (water retting) and fungi (dew retting), chemical retting (dissolve the bonds between the fibres) and mechanical

methods (Mechanical separation of fibres) also known as green retting (Rosa *et al.*, 2010). Each type of retting has certain advantages and disadvantages. Selection of these retting processes depends on the production requirement, location, the equipment and the cost (Torgal *et al.*, 2013).

### **2.2.1. Water Retting**

Water retting is a wet process by which the bundles of cells in the outer layers of the stalk are separated from non fibrous matter by the removal of pectins and other gummy substances (Zhang, 2003) with the help of chemical or microbes present in the retting water (Huang, 2005). In water retting, bundles of mature stems are deposited in water and weighted down with blocks and logs of wood, where a pectinolytic bacterial community is developed. Water retting requires 14 to 28 days to degrade the pectin materials, hemicelluloses and lignin (Schofield and Waller, 2005).

It is the most common method. Water retting require large amount of clean water and therefore more expensive and labour intensive when compared to dew retting. But it results in better quality fibres (Mwaikambo, 2006). The length of the retting process is dependent on the water temperature starts at 12-13°C and a higher temperature accelerates the process (Andresen and Karg, 2011). Water retting is practiced with various techniques.

#### **2.2.1.1. Stagnant Water Retting**

In pool water retting, the size of the pool most convenient to work is about and from 3-4 ft deep. Water retting requires a soft water and water pits. The water pits are placed in an open sunny place. After a few days of fermentation, the stalk floats up on the surface of water due to the formation of carbon dioxide inside the bundles. Iron in the steeping water discolours the fibres, though slight traces do little harm (Murphy, 2003). It is the fastest process and it may take two days to two weeks. But it may easily over-ret and damage the fibre (Rastogi, 2009). In stagnant or tank water retting the process may be performed in three tanks.

- i. In an open tank containing pond water
- ii. In a tank containing pond water and covered with a transparent plastic film (to raise the temperature of the water)
- iii. In an open tank containing well water (Candilo *et al.*, 2000).

### **2.2.1.2. Stream Retting**

Steeping in cool and slow running water produces the better quality fibre. The fibre bundles are covered by straw or jute sack and pressed by stones. In fast running water, bacteria flow away and fermentation process slows down (Arora, 2010). And the stems are placed for 10 to 20 days (Stein, 2008).

### **2.2.2. Dew Retting or Field Retting**

This is the oldest technique as retting of green and dried flax was used by the Egyptians thousands of years ago. Under this technique, plant stems are cut or pulled up and left in the field up to 7-15 days in a thin layer to rot by exposure to dew, rain, wind and sunlight (Franck, 2005). Fresh stems are placed between dried stems while bundling. Fresh stalks rot faster and the microbes that are developed hasten the retting of its co-stalks. Gradually leaves, small branches, loose bark or skin come out of the stalk (Dhanalakshmi *et al.*, 2013).

In dew retting, pectins are attacked by pectinolytic microorganisms, mainly aerobic fungi (Jankauskiene, 2013). Naturally occurring fungi are primarily responsible for retting, with moisture and temperature conditions substantially affecting fungal activity and the quality of retting (Morrison *et al.*, 2000). Temperature is one of the most important factor affecting microbe growth, when temperature is too low the metabolism speed is small, even microbe is in dormancy. While temperature rises, microbe grows faster. But if temperature is too high the growth of microbe will be limited (Yu and Yu, 2007).

It is best done in the spring, as in the late autumn or winter the temperature is often too low. Dew retting otherwise known as field retting is the most common method and least costly method (NIIR Board Consultants and Engineers, 2009).

Disadvantages of dew retting are:

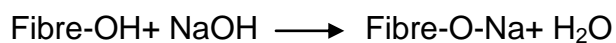
- i. Dependence on particular geographical regions that have the appropriate moisture and temperature ranges for retting.
- ii. Produce coarser and lower quality fibre than water retted fibre.
- iii. Less consistency in fibre characteristics.
- iv. Utilization of agricultural fields for several weeks (Akin *et al.*, 2001).

### 2.2.3. Chemical Retting

Chemical retting consists of softening the tissues and removing non cellulosic components via degumming in alkali solution (remove pectic substances) and scouring via caustic soda (remove residual plant components) to separate the fibre from the woody core. It will shorten the time for retting process (Kalia *et al.*, 2011).

Chemical retting consists of treatment with chelating agents that facilitate removal of pectins and thereby separate the fibres (Henriksson *et al.*, 1999). This is a short retting process, involves the soaking of the stem in aqueous alkaline solutions in an amount proportionate to the fibre. Alkalis such as sodium hydroxide (Keshk, 2006), potassium hydroxide and sodium carbonate are commonly used. The retting is generally conducted at elevated temperatures. A detergent is used to help accelerate the penetration of the alkali into the fibre bundles (Beltran *et al.*, 2002). After treating, it is rinsed with water several times and the obtained bundles of fibres are dried (Zannen *et al.*, 2014).

Chemical retting is a low concentration alkaline solution, and high temperature process. Factors that determine the quality of chemically extracted fibres are the chemical concentration, duration of treatment and temperature (Reddy and Yang, 2005). Alkali treatment of cellulosic fibres, also called mercerization, is the usual method to produce high quality fibres. It improves the fibre- matrix adhesion due to the removal of natural and artificial impurities (Ebisike, 2013).



### 2.2.4. Enzymatic Retting

Enzyme assisted retting is performed by introducing several enzymes in order to enhance the effectiveness of extracting fibres. Enzymes such as pectinase, cellulose and xylanases to the plant stem surface which disintegrate pectin and hemi-cellulose of the plant stem which then separate fibre from the non fibre tissues (Adamsen, 2002). During the environment friendly nature of enzyme retting, enzymes alone may be unable to break the outer layer of productive material to separate the fibre (Thakur, 2014). Prior to enzyme retting, stems are crimped through fluted rollers to disrupt inherent stem barriers (i.e., cuticle or parenchyma) and allow enzyme penetration into the tissues. Fibre separation occurred using a

series of enzyme (pectinase rich) and chelator component formulations (Foulk *et al.*, 2003). The process is carried out under controlled conditions based on the type of enzyme (Tahir *et al.*, 2011).

Enzyme retting is easier particularly for pulping purposes that degrades and provides selective properties for different applications. The enzymatic reactions cause a partial degradation of the components separating the cellulosic fibre from non fibre tissues. The process is faster and cleaner (Akin *et al.*, 2007).

### **2.2.5. Mechanical decortications**

Mechanical separation of fibres is carried out using Decorticating machines, Steam Explosion, Ammonia Fibre Extraction and other novel methods (Gollapalli, 2002). Mechanical decortications have developed in various countries since 1800 AD. Most of them are working on the Raspador system (Ghosh, 2000). It has the combined action of crushing and beating (Msahli *et al.*, 2006). As early as 1900's, people have invented different types of fibre extraction machines that go by different kind of names; decortications, abstraction, de-fibration and others. However they all serve the sole purpose to extract fibre from the plants (Yusof, 2013).

The extraction by the decortications method involves the following operations.

- i. The stalks are cut to appropriate lengths as soon as possible after the harvest
- ii. The stalk is scutched on the drum of the machine.
- iii. The pulp gets separated and fibres are extracted from the machine (Das, 2010).

Decorticating equipment requires few days of immersion in water tanks. Revolving drums are used to separate the fibres from the short woody parts and the pith. The stronger fibres are later washed, cleaned, dried, hackled and combed (Chakrabarti, 2011). The fibres are combed through an army of large nails hammered on a block of wood. The fibres are gathered and straightened out (Brindha *et al.*, 2013).

### **2.3. Biocomposites**

BioComposites are composite material comprising one or more phases derived from a biological region which means they are the combination of natural fibres or Bio-fibres such as wood fibres (hardwood and softwood) or nonwood fibres

(rice straw, kenaf, banana, pineapple, sugarcane, oil palm, jute, sisal and flax) with polymer matrices from both of the renewable and nonrenewable resources (Fowler *et al.*, 2006) because all components eventually break down to water and carbon dioxide after service (John and Thomas, 2008). The mechanical property of the composite depends on interfacial adhesion of fibre to the matrix material (Yousif and Ku, 2012).

### 2.3.1. History

Historically fibre reinforced plastic composites came into use with cellulose fibre phenolics during 1908. Later composites were extended to urea and melamine reaching commodity status during the 1940's with glass fibres in unsaturated polyesters (Mohanty *et al.*, 2005).

Henry Ford has a long history of R&D on new materials. A durability test with a fire axe on prototype first green car made of plastics using 70 percent weight of lignocelluloses fibres derived from soybeans was done. This is the new generation of composite material with the soybean based plastics as an alternative to petroleum based chemical (William, 2000). The Egyptians have also been known to use grass and straw as reinforcing fibres in mud and clay bricks for the building of walls over 3000 years ago (Bledzki *et al.*, 2002).

In recent years, the use of natural or Bio-fibre reinforced composites has rapidly expanded due to the availability of natural fibres derived from annually renewable resources for use as reinforcing fibres in both thermoplastic and thermosetting matrix composites as well as for the positive environmental benefits gained by such materials (Anuar and Zuraida, 2011).

### 2.3.2. Types

Bio-fibre is biodegradable and traditional thermoplastics (PP) or thermosets (unsaturated polyester) being non-biodegradable. The BioComposites from such fibre reinforced polymer come under "**Partially Biodegradable**" type. If the matrix resin or polymer is biodegradable, the bio-fibre reinforced biopolymer composites would come under "**Completely Biodegradable**" type also known as Green Composites. And the third type is two or more bio-fibres in combination on reinforcement with polymer matrix results the "**Hybrid BioComposites**" (Netravali and Chabba, 2003).

### 2.3.3. Fabrication methods

Various fabrication methods have been investigated for BioComposites. These may be classified into two categories according to the types of reinforcement used.

- i. Particle or short fibres and
- ii. Continuous fibres (Roy *et al.*, 2014).

The manufacture of natural fibre containing composites can be manufactured by almost all production techniques. They are processed by simple processing techniques such as hand layup and spraying, compression, transfer, resin transfer, injection, compression injection and pressure bag molding operations. The use of few other methods, such as cold press molding, filament winding, pultrusion, reinforced reaction, injection molding and vacuum forming is hardly reported in the case of composites (Saheb and Jog, 1999).

Several traditional processing methods for thermosetting and thermoplastic polymers have been modified to allow the use of natural fibres. New processing routes have also been developed that allow more rapid fabrication of BioComposites components at production rates demanded by industry (Huber, 2010). There are many ongoing researches to manufacture composites by using natural fibres as reinforcements and polymers from renewable resources as matrices (Oksman *et al.*, 2003). Significant improvements in mechanical properties have also been achieved due to the reinforcing efficiency of fibres coupled with enhancement through chemical modification in order to promote bonding at the fibre-matrix interface (Torres and Cubillas, 2005). The high costs and technical difficulties involved with the fabrication of fibre reinforced composites sometimes limit their use in many applications. Particulate reinforced composites can be thought as a visible alternative (Wanjuan *et al.*, 2007). The particles are easily processed to near net shape and they have the improved stiffness, strength and fracture toughness that is characteristic of continuous fibre reinforced composite materials (Gupta and Woldesenbet, 2001).

The fabrication method plays an important role on the properties. Overall, the molding method was found to be better which preserves and reduce the changes in the physical properties (Bharathykannan *et al.*, 2009).

#### **2.3.4. Uses**

The advantages of natural fibre composites include lack of health hazards and non-abrasive nature (Sreenivasan, 2012). It has increasingly attracted attention because they may be a promising material not only as a novel material for natural resources, eco-friendliness, sustainability, lightness, high molding flexibility, low density, high toughness, comparable specific strength properties, reduction in wear, low energy consumption in fabrication, good mechanical performance, carbon dioxide reduction in nature and cost-effectiveness (Pandey *et al.*,2010). It is an alternative to conventional glass fibre polymer composites in many industrial and commodity applications (Mohanty *et al.*, 2000).

The use of natural fibre composites in automobile interiors also brings about many other benefits, including an increase in safety (the fractures of natural fibre reinforced composites are not as sharp as glass fibre composites) and improved comfort due to the better acoustic and thermal insulation provided by the natural fibres (Miao *et al.*, 2008). These materials could allow complete degradation in soil or by composting process and do not emit any toxic or noxious component (Chen *et al.*, 2005).

#### **2.3.5. Applications**

BioComposites and bio-plastics are used in a wide variety of products, from household to more sensitive and specialized areas of advanced spacecrafts. BioComposites have found in many numbers of applications in the automotive industry (Njuguna *et al.*, 2011) for interior components such as door and instrumental panels (Carus, 2011). For example, glass fibres are replaced with natural plant fibres in some parts of the car (Nadzai, 2006). The natural fibre composites can be very cost effective material for the following applications.

- Building and construction industry: panels for partition and false ceiling, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities.

- Storage devices: post-boxes, grain storage silos, bio gas containers (Pillai and Srikanth, 2011)
- Furniture: chair, table, shower, bath units.
- Electric devices: electrical appliances, pipes.
- Everyday applications: lampshades, suitcases, helmets.
- Transportation: automobile and railway coach interior, boat (Chandramohan and Marimuthu, 2011).

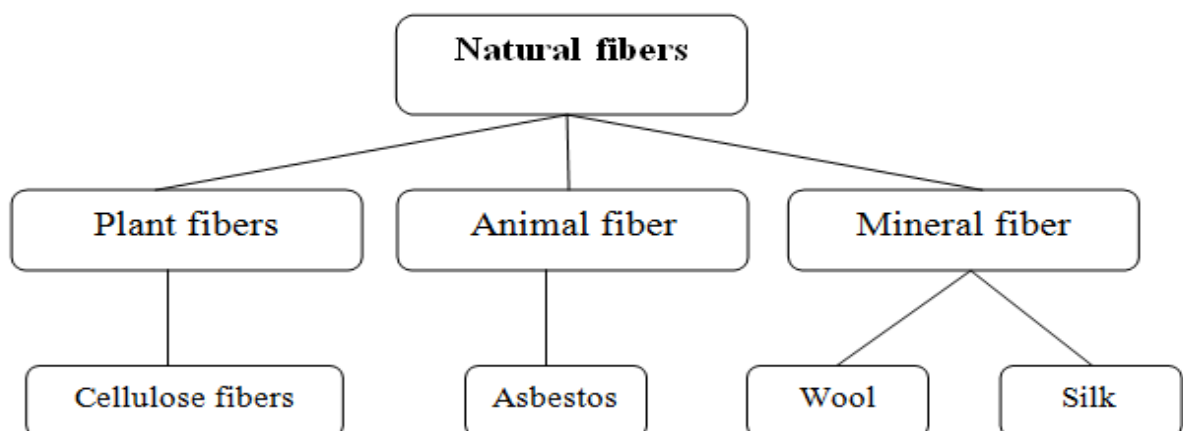
### 2.3.6. Bio fibres

Bio fibres are available in abundance in and around the nature (<http://www.textileschool.com>). Bio fibres or natural fibres classified on the basis of source and chemical composition (Arora, 2010).

- i. Animal fibres: It contains wool, silk, avian fibre. It includes sheep's wool, goat hair, horse hair, feathers and feathers fibre.
- ii. Mineral fibre: Mineral fibres are naturally occurring fibre or slightly modified fibre procured from minerals. These can be further categorized as asbestos, ceramic, metal fibre.
- iii. Plant fibre: Plant fibres are generally comprised mainly of cellulose (Gunti and Atluri, 2013).

**Figure- 1**

**Classification of natural fibres** (Bongarde and Bhide, 2014)

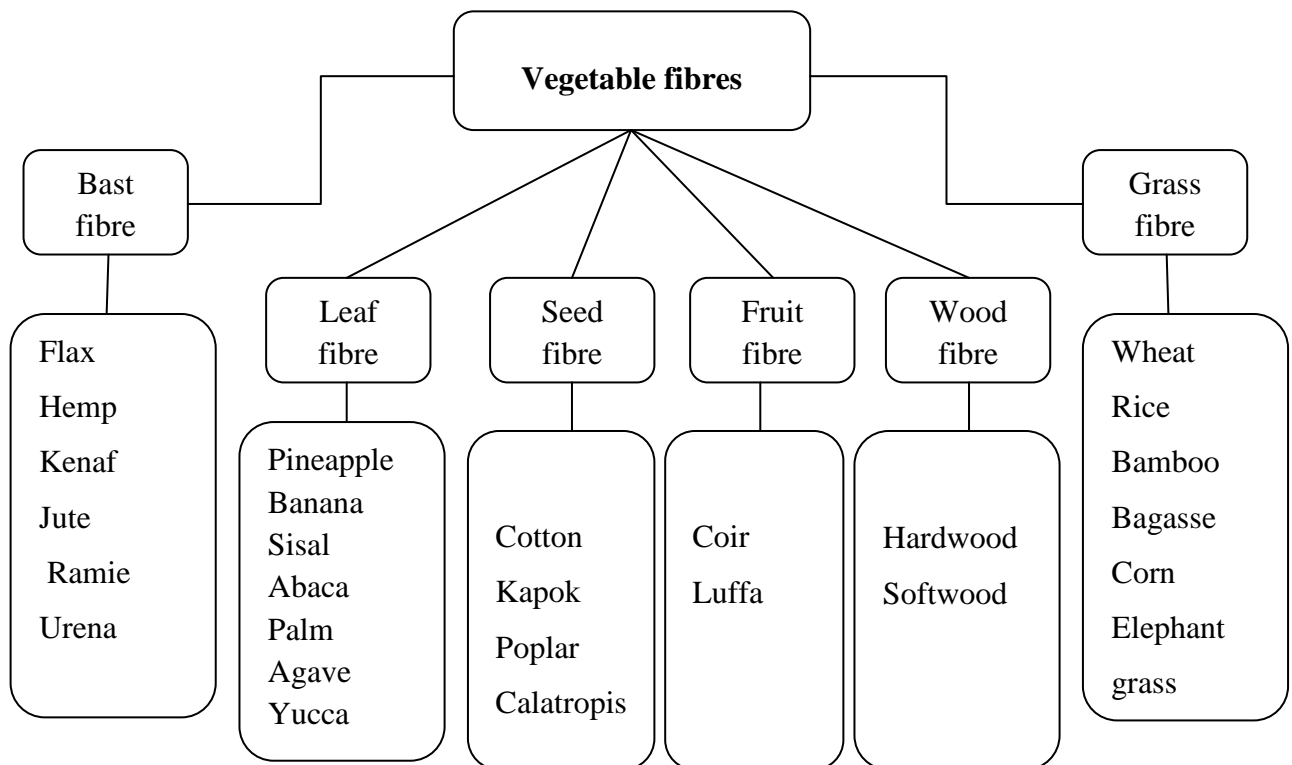


### 2.3.6.1. Vegetable or Plant fibres

The intrinsic characteristics of vegetable fibres are attracting much attention now-a-days (Amico *et al.*, 2010). Plant fibres, which have a long history in human civilization, have gained economic importance and are now cultivated on a large scale globally (Mwaikambo, 2006). Bio fibres can be considered to be composites of hollow cellulose fibrils held together by a lignin and hemicelluloses matrix (Jayaraman, 2003). Plant fibres are classified into bast fibres, leaf fibres, seed fibres, hairy fibre, woody fibres and miscellaneous fibres (Rastogi, 2009).

Fibres from seed and seed case e.g. cotton and kapok known as seed fibres. Fibres from leaves e.g. sisal and agave are known as leaf fibres. Fibres are collected from the skin or bast surrounding the stem known as skin fibres. These fibres have high tensile strength than other fibres. Fibres are collected from fruit of the plant e.g. coconut (coir) fibre known as fruit fibre. Fibres are actually the stalks such as straws of wheat, rice and other crops including bamboo and grass known as stalk fibre. Tree wood is also such a fibre (Bongarde and Shinde, 2014).

**Figure- 2**  
**Classification of vegetable fibres** (Schuh, 2004)



The high strength and modulus of the embedded fibres impart strength and rigidity to the material that surpass that of the neat polymer (Hassen *et al.*, 2004). The most prominent natural fibres used in structural composites are plant fibres because of their specific strength (Zah, 2007). Many factors influence mechanical properties of natural fibres. In many cases, the experimental conditions are different. The mechanical properties of the natural fibre material depend largely on lengths and diameters of individual fibres (Abilash and Sivapragash, 2013).

**Table – II**  
**Properties of natural fibres** (Symington *et al.*, 2009)

<b>Fibres</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Tensile strength (MPa)</b>	<b>Tensile modulus (GPa)</b>	<b>Elongation at break (%)</b>	<b>Decomposition temperature (°C)</b>
Jute	1.3-1.5	187-540	3-55	1.4-3.1	270
Ramie	-	585-900	33	2.0-3.5	260
Hemp	1.4-1.5	580-1,110	3-90	1.3-4.7	258
Bamboo	-	-	1.7-29	3.2	-
Flax	1.4	250-1,000	12-100	1.3-40	280
Sisal	1.4	507-855	24	2.9	270
Cotton	1.5-1.6	350	11	2-10	-
Banana	1.3	791	30	2-10	-
Kenaf	1.4	930	53	-	270
Coconut	-	544	14	-	-

Geometrical dimensions of these fibres, especially the fibre length depends mainly on fibre location within the plant. Fibres from fruits and seeds are few centimeters long, whereas fibres from stems and leaves are much longer (longer than one meter) (Grundas and Stepniewski, 2013). Filament and staple are two terms represent the two basic forms of textile fibres. Filament is a continuous length fibre. Natural filament silk is the example. Staple fibre is the limited length of the fibre (Arora, 2010). A better understanding of the chemical composition and surface adhesive bonding of natural fibre is necessary for developing natural fibre reinforced

composites. The components of natural fibres include cellulose, hemicelluloses, lignin, pectin, waxes and water soluble substances (Rowell, 1997).

Cellulose is a semi crystalline polysaccharide with a large amount of hydroxyl group in cellulose, giving hydrophilic nature to natural fibre when used to reinforce hydrophobic matrices; the result is a very poor interface and poor resistance to moisture absorption (Alvarez, 2003). Hemicellulose is strongly bound to cellulose fibrils presumably by hydrogen bonds. Lignins are amorphous, highly complex, mainly aromatic, polymers of phenyl propane (Bledzki, 2008).

The main drawback of natural fibres is their hydrophilic nature, that prevents their compatibility with hydrophobic polymers used as matrices for the production of composite materials and therefore different kinds of coupling agents have been used for improving interfacial adhesion between polymer matrices and natural fibres in order to enhance the physical and mechanical properties of the final products (Xia *et al.*, 2002).

#### **2.3.6.2. Applications**

Natural fibres have been in structural applications, particularly in rope making, for many years from flax and jute but are currently attracting increasing interest for polymer reinforcement in applications requiring environmentally friendly materials (Beakou *et al.*, 2008). Fibres are utilized in making baskets, chairs and mats known as rough weaving fibres. Fibres used for stuffing, mattresses, cushions, pillows are known as filling fibres. Fabrics, knitted goods and knitted nets can be produced from yarns and wadding, fleeces and felts are produced by aerodynamic or mechanical laying of fibres. Fibres can be used to produce goods such as tarpaulin, geo textiles, bags, carpets or furniture materials (Mussig, 2010).

The utilization of natural fibre has attentions due to the reduction of waste disposal problems especially in agricultural fields, environmental pollution (Nishino *et al.*, 2004) and can find various applications in engineering, electronic and automotive fields (Ovat *et al.*, 2014). In BioComposites the Biofibres serve as reinforcement by enhancing the strength and stiffness to the resulting composite structures (Barghoorn *et al.*, 1998 and Suddel, 2003).

### 2.3.6.3. Advantages

Advantages of the bio fibres over traditional reinforcing materials such as glass fibres, talc and mica (Karnani *et al.*, 1997) are low cost, low density, high toughness, acceptable specific strength properties, reduced thermal and respiratory irritation, good thermal and mechanical properties, ease of separation, enhanced energy recovery and biodegradability and also the Biofibres derived from annually renewable resources (Liu *et al.*, 2012). The sound absorption property of natural fibres was superior to synthetic fibres such as glass and carbon fibres due to their unique hollow and multi scale structures. Natural fibre reinforced composites also possessed better acoustic absorption behaviour than synthetic fibre reinforced composite, especially at high frequencies which might be very beneficial for the aeronautical applications (Yang *et al.*, 2012).

The use of natural fibres at the industrial level improves the environmental sustainability of the parts being constructed, especially within the automotive market. Natural fibres allow insulation properties highly (Rastogi, 2009). Biofibres possess high electrical resistance. Thermal recycling is possible. The hollow cellular structure provides good acoustic insulating properties. The worldwide availability is an additional factor. Natural fibres are also less hazardous to handle and require less energy during processing compared with glass or carbon fibres. The fibres themselves also sequester carbon dioxide during growing and are biodegradable (Mohanty *et al.*, 2002).

The lower mass density of natural fibres (1.4-1.5 g/cm<sup>3</sup> for flax and hemp fibres vs 2.5 g/cm<sup>3</sup> for glass fibres) leads to a reduction in vehicle weight, which in turn leads to a reduction in fuel consumption of the automobile industry (Triki, 2013). Other advantages of utilizing natural fibres are related to their cycle of production that is economical and their ease of processing which demands minor requirements in equipment and safer handling and working conditions with respect to glass fibres (Esfandiari, 2008).

Because of using natural fibres, Natural Fibre Composites can be easily recycled or burned allowing clean energy recovery and avoiding dumping at the end of their life cycle. Therefore, lignocelluloses natural fibres represent an interesting alternative as substitutes for traditional synthetic fibres (Morton *et al.*, 1975). They

need low energy requirements during production. Furthermore, Biofibres show carbon dioxide neutrality and their disposal can be done by composting. Biofibres are non-abrasive and exhibit great formability (Lee *et al.*, 2006).

#### **2.3.6.4. Disadvantages**

- Variable quality due to weather
- Moisture absorption which causes swelling of the fibres
- Limited maximum processing temperature
- Lower strength properties in particular, impact strength
- Lower durability but fibre treatments can improve this considerably
- Poor fire resistance and
- Prices may fluctuate according to harvest results or agricultural politics (Brouwer, 2000).

#### **2.3.7. Biopolymers**

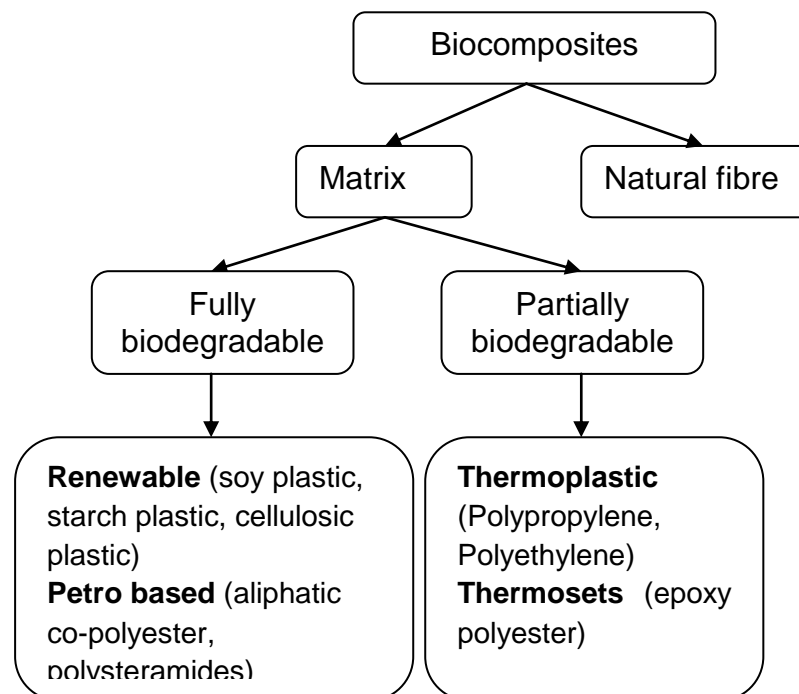
Two different criteria underline the definition of a “biopolymer” (or bio-plastic). The first one is the source of the raw materials and the next one is the biodegradability of the polymer (Niaounakis, 2013). A differentiation can be made between three types of biopolymers.

- i. Biopolymers that are made from renewable raw materials (biobased) and are biodegradable
- ii. Biopolymers that are made from renewable materials (biobased) and are not biodegradable
- iii. Biopolymers that are made from fossil fuels and biodegradable (Kozłowski *et al.*, 2008).

Green polymers also known as bio polymers (Johnson *et al.*, 2003) are derived from natural or agricultural renewable resources. It can be produced by biological systems (microorganisms, plants and animals) or chemically synthesized from biological materials (e.g. corn, sugar and starch). They are also derived from biomass or renewable resources which non-biodegradable. And also from fossil fuel such as synthetic aliphatic polyesters made from crude oil or natural gas and are certified biodegradable and compostable (Averous *et al.*, 2004). No harmful and carcinogenic petrochemicals are used as a polymer matrix to bind the reinforcing fibres together (Prajer *et al.*, 2014).

The development of wholly biodegradable polymers and polymeric materials can play a fundamental role in helping to solve waste disposal problems (Avella, 2008). There are many different polymers of renewable materials. They are thermoplastic starch, Poly-hydroxy-alkanets, Polylactides (PLA), lignin based epoxy and soy based resins as well as epoxidised linseed oil (William, 2000). Among Eco-compatible polymer composites, special attention has been given to polypropylene (Yang *et al.*, 2004).

**Figure- 3**  
**Constituents of natural fibre reinforced polymeric composite materials**  
 (Kozlowski *et al.*, 2004).



Best prospects for applications of biopolymers are currently in the packaging market. Bio-plastics have the potential to capture perhaps 10% of the world polyolefines resin market that is used in packaging and agricultural merchandise, equivalent to 18 million ton per year or more (Kuciel *et al.*, 2010). In addition there could be a market of 5,000 ton per year for agricultural fibres used in building and automotive composites. The price difference between bio-plastics and synthetic plastics is expected to narrow as a result of continued breakthroughs in production and processing technology, increases in base crude oil and close substitute energy prices and government regulations favouring greater use of renewable energy and waste materials (Fowel *et al.*, 2006).

### 2.3.7.1. Polypropylene matrix

Polypropylene (PP) is a plastic polymer with the chemical formula  $C_3H_6$ . The melting point of PP is very high compared to many other plastics, at 320°F (160°C) (NPCs Board Consultants and Engineers, 2014). Polypropylene could not be classified as a biodegradable polymer, but this polymer takes an important place (Srebrenkoska *et al.*, 2014) primarily due to its recyclability, low cost, high thermal stability and good price/ performance ratio (Cho *et al.*, 2006). It is used in many different settings both in industry and in consumer goods and it can be used both as a structural plastic and as a fibre. It shows the most potential benefits when combined with natural fibres in making composites for industrial applications. Car makers are looking increasingly at thermoplastics reinforced with natural fibres to reduce weight and cost in interior and engine components (Kim *et al.*, 2006). Approximately 69.1 million tones of PP were manufactured globally in 2013 (Ye and Yu, 2013).

Mechanical properties of molded polypropylene composites reinforced with randomly oriented short fibre mats is observed that PP reinforced with bast fibres exhibit significantly superior mechanical properties in comparison to leaf and seed fibre reinforced PP (Darshil, 2013). PP can be effectively modified by maleic anhydride, providing polar interactions and covalent bonds between the matrix and the hydroxyl groups of cellulose fibres (Keener *et al.*, 2004). Thermoplastic matrices are increasingly used for industrially fabricated fibre reinforced polymer composites to make more sustainable transportation (Reyes, 2000). The polypropylene has light weight, excellent chemical resistance and recyclable properties (Shubhra, 2010).

PP/natural fibre composites have the potential to replace glass fibre/PP composites (Koronis *et al.*, 2013). For instance, PP/sugar cane composites containing 20% natural fibres have strength of 17 MPa and modulus of 600 MPa, while the modulus of bamboo fibre reinforced PP reaches 2.5 GPa (Gaceva *et al.*, 2007). Bagasse/ PP and china reed/PP composites contribute to further weight reduction and energy saving compared to glass fibre reinforced plastics (Svenneratedt, 2002).

### **2.3.8. Injection moulding**

Injection molding refers to a process that generally involves forcing or injecting a plastic material into a closed mold of desired shape. This method is normally used for high volume and low cost component manufacturing. The injection system consisted of a hopper, a reciprocating screw and barrel assembly, and an injection nozzle. This system confines and transports the plastic as it progresses through the feeding, compressing, melting, injection and packing stages (Srebrenkoska *et al.*, 2009). Both thermoplastic and thermoset are subjected to injection molding (Shubhra *et al.*, 2011). For natural fibre reinforced thermoplastic composites, extrusion-injection molding and compression molding are commonly used (Li *et al.*, 2009).

Injection temperature of lower than 192°C was recommended for better composite quality because at a high temperature, fibre degradation (fibre degradation temperature more or less 200°C) might have occurred, therefore, lead to inferior tensile properties. And it should not be lower than 160°C in order to ensure adequate melting of matrix (Tungjitpornkull and Sombataompop, 2009).

Many researchers fabricated FRPCs by injection molding method. For example, abaca/PP, jute/PP and flax/PP composites were fabricated by (Bledzki *et al.*, 2007) using injection molding method. Similarly, (Arzondo *et al.*, 2005) fabricated sisal/PP, (Karmaker *et al.*, 1996) fabricated jute/PP, (Bledzki *et al.*, 2006) fabricated wood fibre/PP, (Suhara *et al.*, 2007) fabricated hemp glass/PP and (Abraham *et al.*, 2009) fabricated nylon/PP composites using injection molding method.

### **2.3.9. Recent studies**

For the last few years, thermoplastics based natural fibre composites have experienced a tremendous growth in the auto industry. These composite materials have received much commercial success in the semi-structural as well as structural applications. For example, interior parts such as door trim panels from natural fibre and Polypropylene (Quazi *et al.*, 2010). Advantages of thermoplastic NFC over thermo-set based NFC include the greater design freedom, as they are suitable for injection molding and extrusion processing, in addition to the recycling possibilities (Shubhra, 2010).

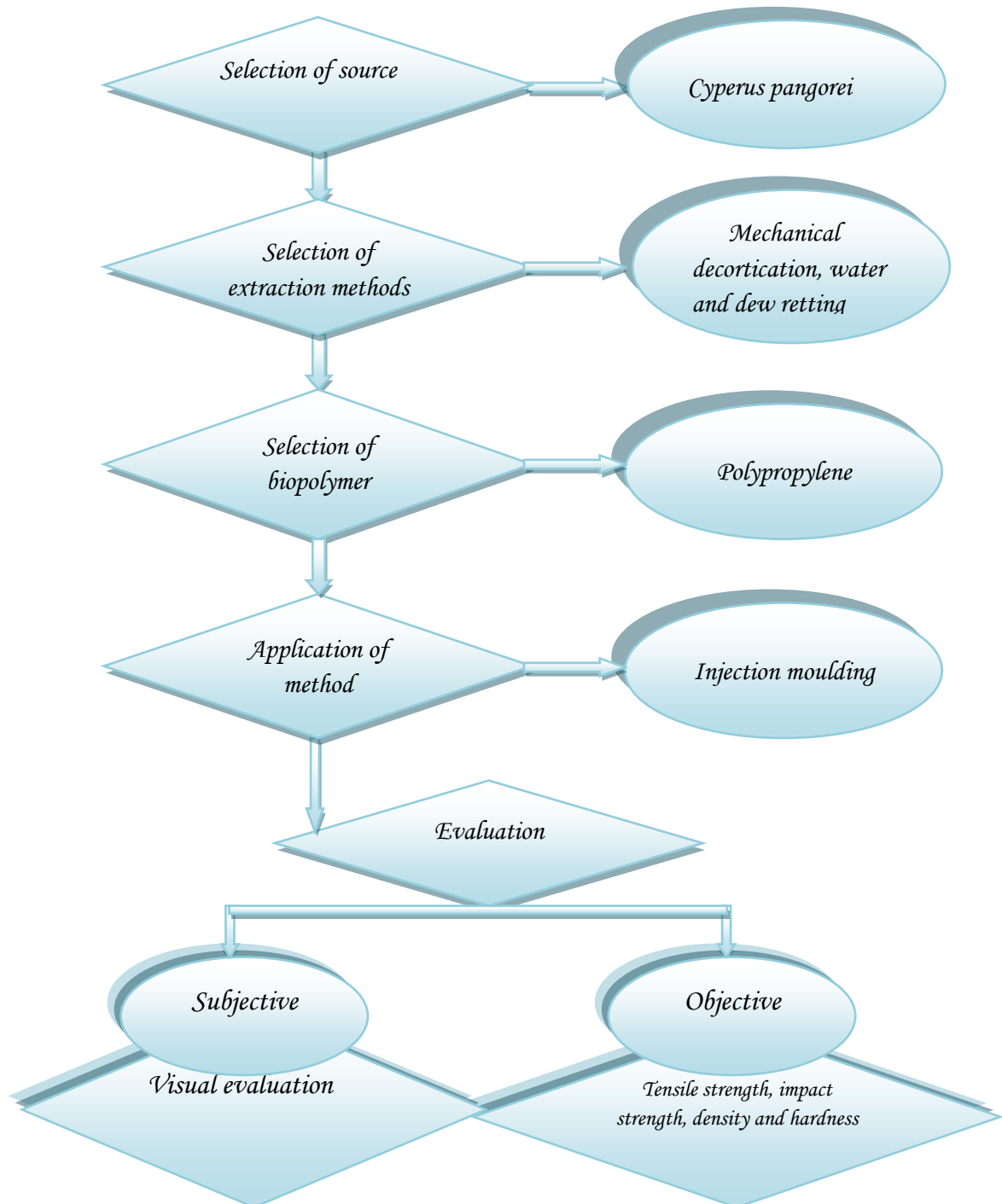
By commercial application, over 95% of plant fibre reinforced products produced in the EU is used for non-structural automotive components (Carus, 2011). In the case of polymer BioComposites, a particular interest is focused on natural fibres derived from plants (Faruk *et al.*, 2012). The extensive intermolecular hydrogen- bonding potential resulting from the surface rich in hydroxyl groups, cellulose has the potential for strong interaction with polar thermoplastics polymers (Maghchiche, 2013). Since the plastics are soft, flexible and lightweight compared to natural fibres, their combination provides a high strength to weight ratio to the resulting composite (Shehu, 2014).

### 3. EXPERIMENTAL PROCEDURE

The experimental procedure carried out in the study “*Cyperus pangorei*- A Natural Fibre for Biocomposites” consists of the following headlines:

- 3.1. Selection of source
- 3.2. Collection of source
  - 3.2.1. Preparation of source
- 3.3. Retting methods
  - 3.3.1. Water retting
  - 3.3.2. Dew retting
  - 3.3.3. Chemical retting
  - 3.3.4. Mechanical decortications
- 3.4. Nomenclature
- 3.5. Evaluation of fibre
  - 3.5.1. Subjective evaluation
  - 3.5.2. Objective evaluation
  - 3.5.3. TGA analysis of fibre
  - 3.5.4. SEM analysis of fibre
- 3.6. Biocomposites preparation
  - 3.6.1. Preparation of required material
  - 3.6.2. Preparation of pellets
  - 3.6.3. Fabrication of composites
- 3.7. Evaluation of Biocomposites
- 3.8. Statistical analysis

## RESEARCH DESIGN



### **3.1. Selection of source**

Natural fibres are well accepted reinforcement materials with the capability of replacing synthetic fibres such as glass and carbon fibres in polymer matrix composites. Natural fibres based on cellulose have a low density and are relatively stiff and strong. Their specific mechanical properties are rather high and actually comparable to those of glass fibres (Prabhakaran *et al.*, 2014).

To look for new plants that enable easy and cost effective research *Cyperus pangorei* was selected as a source. It was selected because it is available in huge quantity and represents a great potential. On the other hand, these materials are generated worldwide and their renewable character, pave a new route for its exploitation. *Cyperus pangorei* (Plate-I) is also called as korai grass known for its unique properties, cool in summer and warm in the colder climates.

### **3.2. Collection of source**

The fully grown (height up to 3 ½ feet to 4 feet) matured *Cyperus pangorei* was harvested and collected from the banks of river, Pudhur region, Karur district, Tamil Nadu. The maturity of the korai grass is identified by flowers at the end of the Culm strands and they were selected. It was harvested while it was still green.

#### **3.2.1. Preparation of Source**

The cyperus pangorei was sorted by selecting the matured stems. The matured stem was utilized for extraction (Plate-II). The flower at the top of the stem was cut down and the brown or purple sheaths at the lower region were removed from the Culm strands.

### **3.3. Retting methods**

#### **3.3.1. Water Retting**

Water retting is a microbial process that breaks the chemical bonds that hold the stem together and allows separation of fibres from the woody core. This is usually affected by the combined activity of the water and the microorganisms (Pooja, 2010). Several aerobic bacteria such as bacillus subtilis, micrococcus sp, and anaerobic bacteria such as clostridium tertium, c.aurantibutyricum, and c.felsineum have been isolated from retting water and were found effective in retting process (Lichtfouse, 2012).

The full length of *Cyperus pangorei* was cut down into the required length of 10 cm and soaked into the open water tanks for 4 weeks. The size of the water tank is 5 feet in length and 4 feet in width and 2 feet in depth. The fibres were bundled and weighted with stones for well soaking (Plate-III). After 4 weeks (Plate-IV) the bundles of stems were taken out and washed thoroughly with cleaned water. The fibres were separated from the stems and then it was dried under the shade (Plate-V).

### **3.3.2. Dew Retting**

Dew retting is carried out in the spring, under conditions of moderate humidity, warmth, and freedom from wind. Mold and other fungi are the active retting agents. The process takes anywhere from 3 to 7 weeks, depending on the fungi and bacteria present in the soil and on weather conditions (Lewin, 2006).

The stem was collected in early autumn at the latest to avoid difficulties in drying. After harvesting the *C. pangorei* stems were spread evenly in a grassy field reserved for the purpose. Once a week, the strands were turned to ensure even retting. The retting process was monitored carefully to ensure that the fibres separate from the inner core without much deterioration in quality. This process was done for 15 days. Then the fibres were separated by hackling the stems (Plate-VI).

### **3.3.3. Chemical Retting**

Ahmed and Akhter (2001) were of the opinion that chemical retting causes dissolution of tissue materials (softening of tissues due to degradation of lignin, hemicelluloses and pectin) with certain chemicals such as boiling with acid (0.5%  $H_2SO_4$ ) or alkali (1% NaOH) at a normal or high or boiling temperature for 6-8 hours and the fibres obtained by this method have been found little coarser, rough and stiff.

Proper vessel was taken and filled with the required amount of water to soak the stem. Alkali solution was added into the water. The stem tissues were softened by boiling with 1.0% sodium hydroxide for 6-8 hours. It was boiled to speed up the function of retting. After the treatment the fibres were washed with clean water. Then it was combed to remove the fibres. The fibres were dried under the shade (Plate-VII).

### 3.3.4. Mechanical decortications

The mechanical separations of fibres are carried out using decorticating machine. In this green stems are cut from the plant and crushed and beaten by a rotating wheel set with blunt knives. This process is known as decortications. This process offers the advantage of separating the plant components without disintegrating their constituents, which can be further treated to extract fibres and other bio-products (Reddy and Yang, 2005).

The pre-prepared samples of cleaned and matured cyperus pangorei stems were feed into the mechanical decorticator (Plate-VIII). The lower part of the stem is thick in diameter compared to the upper part. Therefore the lower part of the stem is feed into the machine. Initially the stems were feed into the feed table. The feed table was adjusted to feed the fibre easily and comfortably. And it was passed through the revolving cylinder. After passing  $\frac{3}{4}$ <sup>th</sup> of the stem the machine is stopped and then pulled out again. So as to loosen and cleaned the fibre from the stem by holding the materials. For the easy separation the revolving rollers have a number of blunt knives which are used to split the stems during speedy rotation. Then it was combed and dried under the shade (Plate-IX).

### 3.4. Nomenclature

**Table-III**  
**Nomenclature**

<b>S. No</b>	<b>Nomenclature</b>	<b>Abbreviation</b>
1.	Water Retted Fibre	WRF
2.	Dew Retted Fibre	DRF
3.	Chemical Retted Fibre	CRF
4.	Mechanically Decorticated Fibre	MDF

### **3.5. Evaluation of fibre**

#### **3.5.1. Subjective Evaluation**

The stiffness and smoothness of the fibre can be evaluated by hand. Hence the visual evaluation was done to obtain the opinion and preferences of the retted samples. A score card was prepared. The retted samples were neatly covered and evaluated by 20 judges comprising of PG students of Textiles and clothing department, Avinashilingam institute for home science and higher education, Coimbatore. They were asked to score the extracted fibre for general appearance, brightness, texture and evenness. The prepared score card is presented in the Appendix i. The results are discussed in chapter IV.

#### **3.5.2. Objective Evaluation**

##### **3.5.2.1. Fibre length**

Fibre length is the most important property of a fibre. Textile fibres are either staple or filament. Short staple fibres range from 2 to 46 cm, filament are of infinite length (Mussig, 2010). The extracted fibre length was measured using scale.

##### **3.5.2.2. Fibre crimp**

Crimp refers to waves, bends, twists or curls along the fibre length. It is expressed as crimps per unit length. Some natural fibres are linear; others form two-dimensional or three-dimensional crimps. Crimped fibres tend to have higher elongation than linear fibres. The fibres were observed well for its crimp.

##### **3.5.2.3. Fibre identification by burning**

The selected grass fibre was cut down into the length of 2 cm. The fibre was held in tweezers and brought slowly to the side of the flame. The performance was carefully watched and the information was recorded (Fan, 2005).

##### **3.5.2.4. Fibre identification by solubility**

The test sample of fibre was taken. Three test tubes are filled with 10% of caustic soda at room temperature, 10% of caustic soda at 40°C and 70% of sulfuric acid at 40°C respectively. The fibres were put into the test tube for 20 minutes. After that the changes were noted.

### **3.5.2.5. Tensile Strength and Elongation**

Performances of fibres under different forces and deformations, which are applied along its longitudinal axis, are defined as the tensile properties of fibres. The Tex system is widely used by textile manufactures for expressing the linear density of raw materials and yarn products. Fibre breakage can be expressed by the percentage of elongation too. In other words, the breaking elongation gives a measure of the resistance of the material to elongate and finally break. It means how much the fibre will extend or elongate for the break to occur. It is an essential and critical property when a fibre is subjected to stretching. Fortunately, unlike the strength which can be stated in different units, elongation to break is simply normalized as fractional strain or percentage extension (Shahzad, 2013).

As per the ASTM standard (D 2556/2556 M-2010) the fibre breaking force and elongation test was carried out by using TEXTECHNO H-STEIN GmbH standard Tensile Strength Tester (Plate-X). Initially the required details are uploaded into the computer. The details included operator name, name of the tested sample, the number of samples to be tested, and pre tension. Then the appropriate jaw was fixed to the tensile strength machine. Each sample of fibre with 160 Tex was clamped between the upper jaw and the lower jaw. The lower jaw is an adjustable and movable jaw. So it is adjusted to the length of the fibre. The gauge length was 500 mm and the load cell applied was 10 N. After switching on the machine, the movable jaw was started to move to break the fibre. The readings were noted for the strength in MPa and the elongation in percentage as soon as the sample was broken. Similarly 30 samples were tested. The readings were taken and the mean breaking strength and elongation was found.

### **3.5.3. TGA analysis**

The samples were analyzed using a thermal analyzer. All the measurements were made under a nitrogen flow, keeping a constant heating rate of 10°C per minute and using an alumina crucible with a pinhole. The sample was tested up to the temperature of 650°C (Singa and Thakur, 2008).

### **3.5.4. SEM Analysis**

Scanning Electron Microscopy (SEM) is a method for high- resolution imaging of surfaces. The SEM uses electrons for images that are more than 0.2  $\mu\text{m}$  in diameter, much as a light microscope uses visible light. The electron lenses used to focus the beam on the specimen. The advantages of SEM over light microscopy include much higher magnification (>100,000X) and greater depth of field upto 100 times that of light microscopy (Reed, 2005). The mechanically decorticated fibre was examined and the detail is presented in results and discussion chapter.

### **3.6. Biocomposites preparation**

Biocomposites are composite materials comprising one or more phase(s) derived from biological origin (Kuciel *et al.*, 2010).

#### **3.6.1. Preparation of required Material**

The extracted length of the fibre from *cyperus pangorei* by using mechanical decortications method, water retting and chemical retting, were chopped into short lengths of 4 mm approximately to ensure an easy blending (Plate-XI). Prior to compounding the chopped fibres were dried in an oven at 60°C for 4 hours. This is to reduce the moisture present in the fibres. The moisture content reduction of the fibre was tested for four hours.

In this work, the thermoplastic polypropylene was used because of its cost effectiveness, availability, light weight, good mechanical properties, excellent moisture, heat and chemical resistance, excellent dielectric properties, favourable processing and recycle characteristics and relatively low price (Karian, 2003). PP granules (Plate-XII) with a melting temperature of 160°C were selected (NPCs Board Consultants and Engineers, 2014).

#### **3.6.2. Preparation of pellets**

Before using injection molding machine fibres and matrix were mixed in twin extruder device. Co-rotating twin screw extruder machine, ZE-25 model Berstorff Maschienban GmbH, D-3000 Hannover, Germany was used (Plate-XIII). By using this, the pellets were formulated. The gravimetric feeder was used to feed the polymer and the dried fibres. Both materials were added to the machine at the same time with a weight ratio of 30:70 (Grass fibre: Polypropylene). The polymer and fibre

mixture was compounded at a maximum temperature of 190°C which is above the melting point of thermoplastic matrix for 15 minutes and a screw speed of 100 rpm in the twin screw extruder. In the die zone the 5mm gauge circular die was fitted to get the circular pellets. The strands were dried and subsequently pelletized (Plate-XIV) using a pelletizer (Asaithambi *et al.*, 2014).

**Table IV**  
**Processing parameters using twin screw extruder**

Parameters	Settings
Screw speed (rpm)	100
Screw diameter (mm)	25
Screw L/D ratio	48:1
Temperature profile (°C)	
Zone 1	150
Zone 2	155
Zone 3	160
Zone 4	165
Zone 5	170
Zone 6	175
Zone 7	180
Zone 8	185
Zone 9	190

### **3.6.3. Fabrication of composites**

All the pelletized formulations were injection molded in a JSW injection moulding machine (Plate-XV) to get the Biocomposites material. The pellets were feed into the feeding chamber known as hopper of the machine by using gravimetric force. Then it is passed to the barrel. Here the heating chamber was placed. To

avoid the thermal degradation, the temperatures in the three main zones of the equipment were carefully selected ranging from 160-220°C. The melted material was mixed well into the screw. From the feed zone the material was passed to die zone by the use of nozzle. The injection pressure was 60MPa and the cycle time was 30 seconds. The time intervals for the packing and cooling stages were 30 and 25 seconds respectively (Esfandiari, 2008). The specimens were prepared (Plate-XVI).

### **3.7. Evaluation of Biocomposites**

The important mechanical properties tensile strength, impact strength, density and hardness were tested. All test specimen dimensions were according to the respective ASTM standards. All tests were performed at room temperature. Five specimens of each type were tested and five replicate values were taken as an average of tested specimens.

#### **3.7.1. Tensile strength and elongation**

In a broad sense, tensile test is a measurement of the ability of a material to withstand forces that tend to pull apart and to what extent the material stretches before breaking. The stiffness of a material represented by tensile modulus can be determined from stress-strain diagram.

Tensile test was performed at a room temperature using Universal testing machine (Plate-XVII) according to ASTM D638 standards. The standard type IV dumbbell shaped specimens were used in the testing. The specimens were positioned vertically in the grips of the testing machine. The grips were tightened evenly and firmly to prevent any slippage with gauge length kept at 50 mm. It was carried out at a cross-head speed of 5mm/min and the dimensions of test samples were 167×13×3 mm. Five samples were tested to get the accurate value (Kim *et al.*, 2006). Tests were carried out at room temperature and each test was performed until tensile failure occurred.

$$\text{Tensile strength} = \frac{\text{Force(load)}}{\text{Cross section area}}$$

### 3.7.2. Impact strength test

Impact strength is the ability of a material to resist breaking under a shock loading or the ability to resist fracture under stress applied at high speed. Impact properties of the materials are directly related to the overall toughness of the material. Toughness means the ability of the polymer to absorb applied energy. Five samples with specified dimensions and defined notches were prepared (Jeyanthi and Rani, 2012).

Impact tests were performed at a room temperature using Impact testing machine (Plate- XVIII). Charpy impact test methods were conducted according to the ASTM D 256 standards. The rectangular specimen with the dimensions of 65×13×3 mm was taken and notched by using notching cutter machine. Before the test the samples were tested, the machine was calibrated. The test samples were then gripped and the force required to break the bar was released from the freely swinging pendulum. The value of the angle through which the pendulum has swung before the test sample was broken corresponded with the value of the energy absorbed in breaking sample and this was read from the calibrated scale on the machine (Dagwa *et al.*, 2014).

### 3.7.3. Density test

The theoretical density of the composite materials in terms of weight fraction can be easily calculated as in the following equation given by agarwal and broutman (1990).

$$\rho_{ct} = \frac{1}{\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right)}$$

In this, w and  $\rho$  represent the weight fraction and density of the fibre and matrix material. Density was measured using the gravimetric method g/cm<sup>3</sup>.

Float type Density tester (Plate-XIX) was used measure the density of the biocomposites material. The tests were conducted at a room temperature. A known inner volume of glass cylinder was taken. The glass cylinder was equipped with two automatic sensors which control the cylinder full or empty. Composite samples were dried before measurement. The dry sample mass was taken while the glass cylinder

was full. The density was calculated by dividing the dry mass of each sample by the known volume of glass cylinder. (Sakthivel and Ramesh, 2013). Five samples were tested for the mean value of the composite material.

#### **3.9.4. Hardness test**

Hardness is the important surface property. Hardness represents the viscoelastic response of a material (Biswas *et al.*, 2012).

The hardness test was conducted at a room temperature by using Shore (D) Hardness tester (Plate-XX) the diamond indenter by applying a load of 10 N. Five samples were tested.

#### **3.10. Statistical analysis**

Analysis of variance (ANOVA) was used to analyze the results of tensile tests, impact tests, density and hardness test. SPSS software package was used.



Plate- I *Cyperus pangorei*



Plate-II Processed matured stems



Plate –III Figure before water retting



Plate- IV Fibre after water retting



Plate-V Water retting of fibre



Plate-VI Dew retting of fibre



Plate-VII chemical retting of fibre



Plate-VIII Mechanical decorticator



Plate-IX Mechanical decortication  
of fibre



Plate-X Tensile strength machine



Plate-XI Chopped korai  
Grass fibres



Plate-XII Polypropylene  
granules



Plate-XIII Twin screw extruder



Plate-XIV Formulated pellets



Plate-XV Injection molding machine



Plate-XVI Fabricated Specimens



Plate-XVII Tensile strength tester  
(Composites material)



Plate-XVIII Charpy Impact  
strength tester

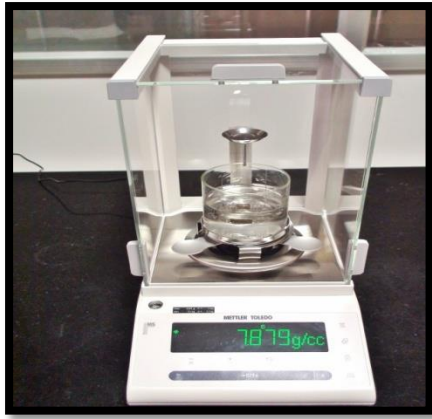


Plate-XIX Float type density tester



Plate-XX Shore (D) Hardness tester  
Durometer

## 4. RESULTS AND DISCUSSION

The Results and discussion pertaining to the study entitled “*Cyperus pangorei*- A Natural Fibre for Biocomposites” is discussed under the following headings

4.1 Subjective Evaluation

4.2 Objective Evaluation

### 4.1. Subjective evaluation

The visual evaluation result of the water retted, dew retted, chemical retted and mechanically decorticated samples are presented in the Table V.

**Table-V**  
**Visual evaluation**

S. No	Samples	General appearance			Texture			Brilliancy of colour		
		E	G	F	S	M	C	H	M	L
1	WRF	85	15	-	75	20	5	70	20	10
2	DRF	-	-	100	-	-	100	-	-	100
3	CRF	80	20	-	80	15	5	85	15	-
4	MDF	90	5	5	85	10	10	80	10	10

E- Excellent, G-Good, F-Fair, S-Soft, M-Medium, C-Coarse, H-High, M-Medium, L-Low.

From the above Table V, it is clear that the general appearance was rated to be excellent for the sample MDF by 90% of the respondents followed by the samples WRF and CRF by 85 and 80 % respectively. Regarding texture, MDF sample was observed to be soft as expressed by 85 percent of the respondents followed by CRF and WRF by 80 and 75 percent respectively. Minimum of 85 percent of judges has suggested sample CRF to be brilliant in colour with respect to its whiteness whereas, the minimum brilliancy in colour was observed in sample WRF by 70 percent. From among these criteria's, all the respondents have suggested sample DRF to be fair in appearance, coarse in texture and low in brilliancy of colour.

Hence it could be concluded that the sample MDF was found to be better than samples WRF, DRF and CRF in general appearance and texture whereas the increase in brilliancy of colour in CRF sample might be due to bleaching of colour by sodium hydroxide.

## 4.2. Objective evaluation

### 4.2.1. Fibre length

The average length of the fibre was measured using a measuring scale. The results shows that the mechanically decorticated fibre measures 70cm-1m long whereas the length of the water retted fibre and chemically retted fibre was 53-90 cm and 40-83 cm respectively.

It is observed that the fibre length is maximum in mechanically decorticated fibre.

### 4.2.2. Fibre crimp

The water retted, chemical retted and mechanically decorticated fibres have no crimp when visually observed.

### 4.2.3. Fibre identification by burning test

**Table- VI**  
**Burning of fibre**

<b>Initial reaction</b>	<b>Burning</b>	<b>Description of flame</b>	<b>Odour</b>	<b>Remains</b>
Starts to flame	Burns without flame	Flame is in the colour of greenish yellow	Burns resembles smell of burnt paper	Leaves delicate black ash smouldering to blue colour

From the Table VI, it is clear that the fibre *cyperus pangorei* reacted to flame is related to grass fibre family. It leaves delicate black ash as residue and also resembles the smell of burnt paper. These indications suggest that the fibre is related to grass family.

#### 4.2.4. Fibre identification by solubility test

**Table-VII**  
**Solubility of fibre**

<b>Chemical concentration</b>	<b>Immediate effect</b>	<b>After 10 minutes</b>	<b>After 20 minutes</b>
<b>NaOH 10%(Room temperature)</b>	Floating of the fibre	The colour of the fibre is slightly changed.	Fibre is not soluble but many changes were occurred such as bleaching of fibre and strength loss.
<b>NaOH 10%(40°C)</b>	Floating of fibre	The colour of the fibre changes and sinks.	The total colour of the fibre is changed and the fibre was half degraded.
<b>Sulfuric acid 70% (40°C)</b>	The fibre sinks into the sulfuric acid	Half degradation of fibre	Fully degraded into the sulfuric acid.

The solubility test of fibre is mainly carried out using NaOH and sulfuric acid. Based on the results from the Table VII, it is evident that the fibre floated over the solution immediately after drop and then resulted in a slight colour change after 10 minutes. But finally, the fibre showed no solubility even after 20 minutes and resulted in strength loss and bleaching.

The fibre subjected to solubility in 10% NaOH at 40°C. Floats immediately after drop showing similar effect as observed in the solubility of fibre in 10 percent of NaOH whereas the colour of the fibre changes as well as it sinks after 10 minutes in 40 percent NaOH. After 20 minutes of solubility, half degradation of the fibre was noticed only when the temperature is raised to 40°C.

The result of fibre solubility in 70% sulfuric acid at 40°C shows an immediate effect of the fibre sinking in sulfuric acid. After 10 minutes, half degradation of the fibre had occurred, whereas drastic degradation of fibre was observed after 20 min.

#### 4.2.5. Assessment of mechanical properties

The mechanical properties of the fibre were analyzed for tensile strength and elongation, tenacity and work to rupture.

##### 4.2.5.1. Tensile strength of fibres

The results of the fibre strength of the water retted, dew retted, chemical retted and mechanically decorticated are presented in the Table VIII and Figure 4.

**Table- VIII**  
**Tensile strength of fibres**

S. No	Samples	Mean strength (in MPa)	Standard deviation	“F” ratio
1.	WRF	212.08	72.2423	2.944*
2.	CRF	201.21	61.6047	
3.	MDF	277.20	90.5451	

\*- 1% significance level

From the above Table VIII it is clear that the sample MDF shows the maximum strength by 277.20 followed by the sample WRF with its mean value as 212.08 and CRF as 201.21. The least value based on the tensile strength is seen in the sample CRF and highest in MDF. The reason for an increase in strength by the sample MDF may be due to the absence of chemicals during fibre extraction. The MDF sample utilizes only decorticator that involves mechanical fibre extraction technique, thereby maintaining the actual properties of the fibre whereas the CRF technique involves chemicals that deteriorate the fibre properties during extraction. The reason for WRF sample to show decrease in strength when compared to MDF sample may be because of the prolonged immersion of the fibres in the water. The statistical analysis pertaining to the sample's tensile strength of samples show significant difference at 1 percent level.

Hence it could be concluded that the sample MDF has the maximum strength when compared to other fibre processing. In order to identify the strength quality of korai grass fibre, the same was compared with the strength of other fibres. The result from the Figure 4 shows that the selected fibre shows a decrease in strength when

compared to sisal, hemp, jute, flax and kenaf with their values noted to be 510, 690, 393, 344 and 930 respectively.

From Figure 5, it is understood that the sample korai grass shows a decrease in strength when compared to the other fibres strength such as jute, flax, sisal, hemp, kenaf with the values of 393, 344, 510, 690 and 930 respectively (Pandey *et al.*, 2010).

#### 4.2.5.2. Elongation of fibres

The results of the fibre elongation of the water retted, chemical retted and mechanically decorticated are presented in Table IX and Figure 6.

**Table IX**  
**Elongation of fibres**

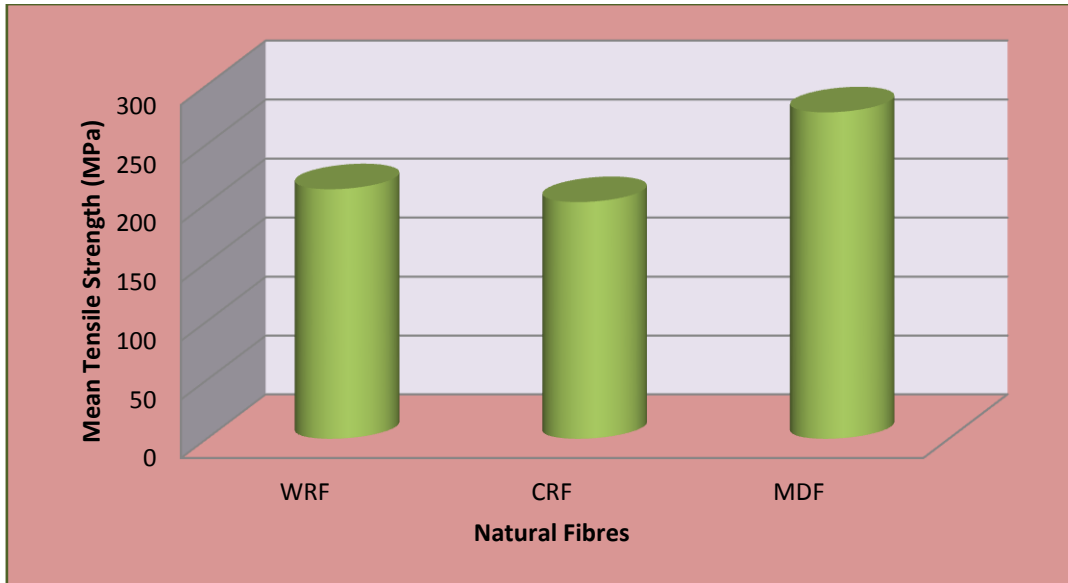
S. No	Samples	Mean Elongation (%)	Standard deviation	“F” ratio
1.	WRF	0.719	0.353	2.850*
2.	CRF	0.716	0.310	
3.	MDF	1.045	0.395	

\*- 1% significance level

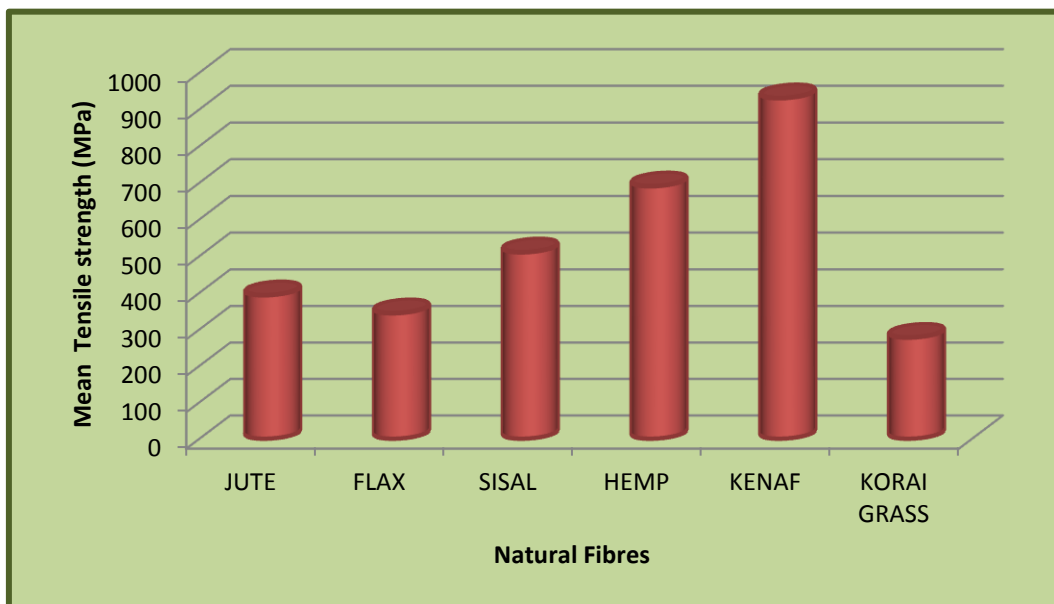
It is clear from the Table IX that the sample MDF shows the maximum elongation percentage as 1.045 followed by the sample WRF with its mean percent elongation as 0.719 whereas least values based on the fibre elongation is seen in sample CRF with 0.716. From the above listed sample, though WRF sample shows an increase in elongation when compared to CRF sample, it is low when compared to MDF. Thus the statistical results of fibre elongation of samples show significant difference at 1 percentage level.

Hence it could be concluded that the sample MDF has the maximum elongation when compared to WRF and CRF.

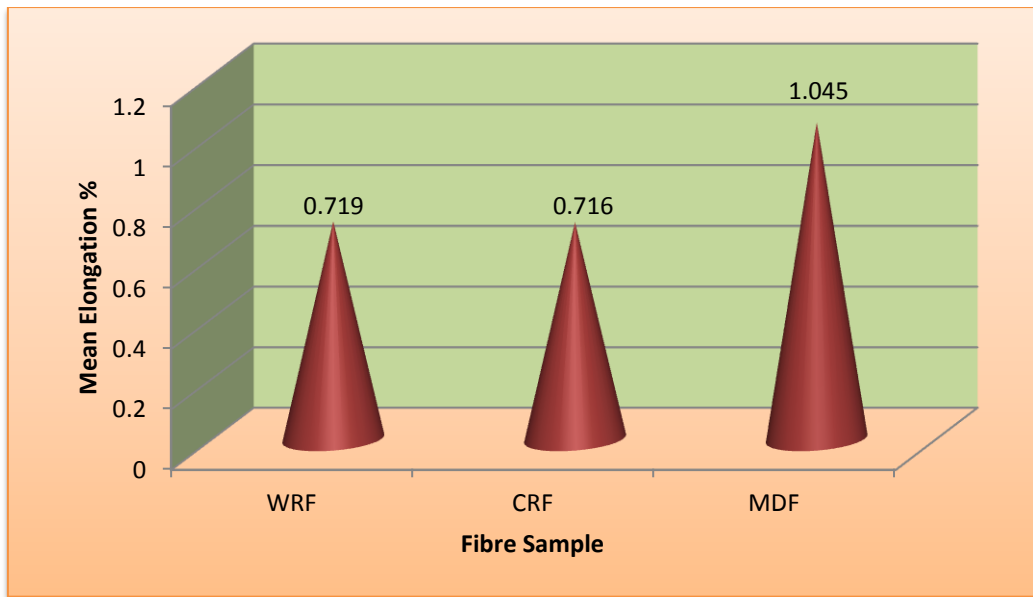
From Figure 7, it is evident that the sample korai grass shows a decrease in elongation when compared to the other fibres strength such as jute, flax, sisal, hemp, kenaf with the values of 1.5, 3.2, 5, 3, 1.6, 0.5 and 1.05 respectively (Pandey *et al.*, 2010).



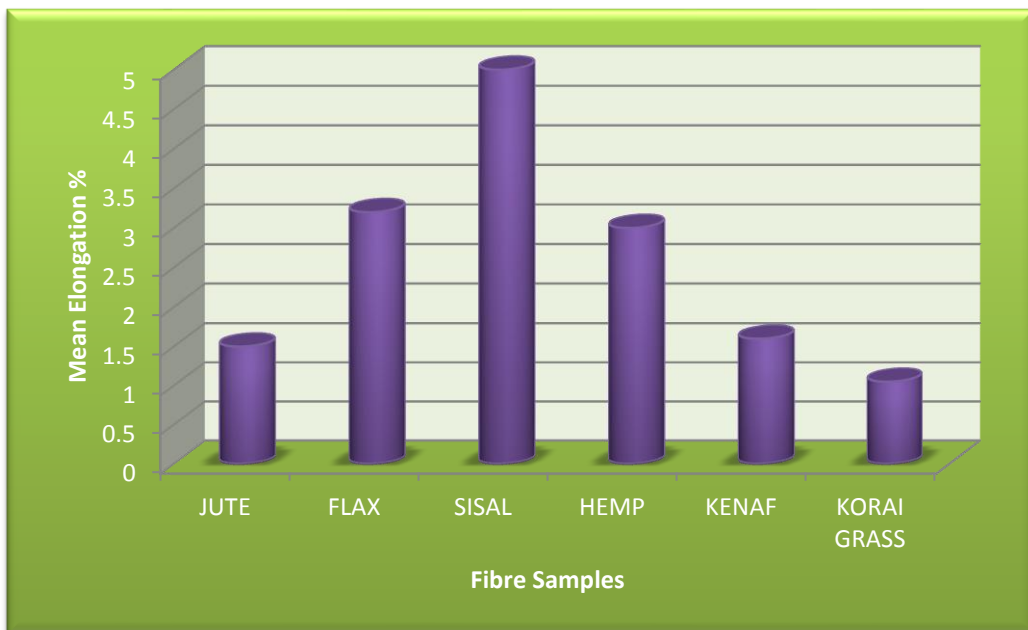
**Figure- 4**  
**Tensile strength of fibres**



**Figure- 5**  
**Tensile strength of korai grass in Comparison with other natural fibres**



**Figure- 6**  
**Elongation of fibre**



**Figure- 7**  
**Elongation of korai grass in Comparison with other natural fibres**

#### 4.2.5.3. Tenacity of fibre

The results of breaking tenacity of the fibre of the water retted, dew retted, chemical retted and mechanically decorticated are presented in the Table X and Figure 8.

**Table X**  
**Tenacity of fibre**

S. No	Samples	Mean tenacity (in Rkm)	Standard deviation	"F" ratio
1.	WRF	1.3260	0.45083	2.588*
2.	CRF	1.2590	0.38587	
3.	MDF	1.7100	0.57820	

\*- 1% significance level

From the above Table X and Figure 8, it is obvious that the breaking tenacity of samples was the maximum in sample MDF as 1.71 Rkm followed by samples WRF as 1.326 Rkm. Statistically it is confirmed that there is a significant difference at 1% level with 'F' value of 2.588.

Hence it could be concluded that tenacity of the mechanically retted fibre increased when compared to WRF and CRF.

#### 4.2.5.4. Work to rupture resistance of fibre

The results of work to rupture of the fibre of the water retted, dew retted, chemical retted and mechanically decorticated are presented in Table XI and Figure 9.

**Table- XI**  
**Work to rupture resistance of fibre**

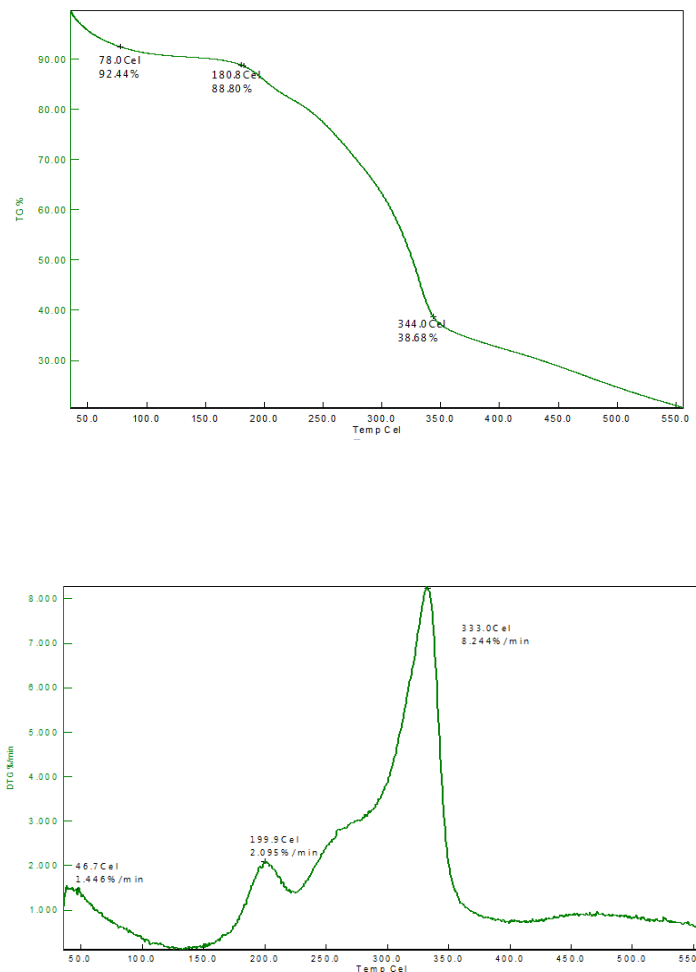
S. No	Samples	Mean (MJ/tex-m)	Standard deviation	"F" ratio
1.	WRF	59.39	41.8767	3.544*
2.	CRF	55.81	30.2776	
3.	MDF	103.22	56.8248	

\*- 1% significance level

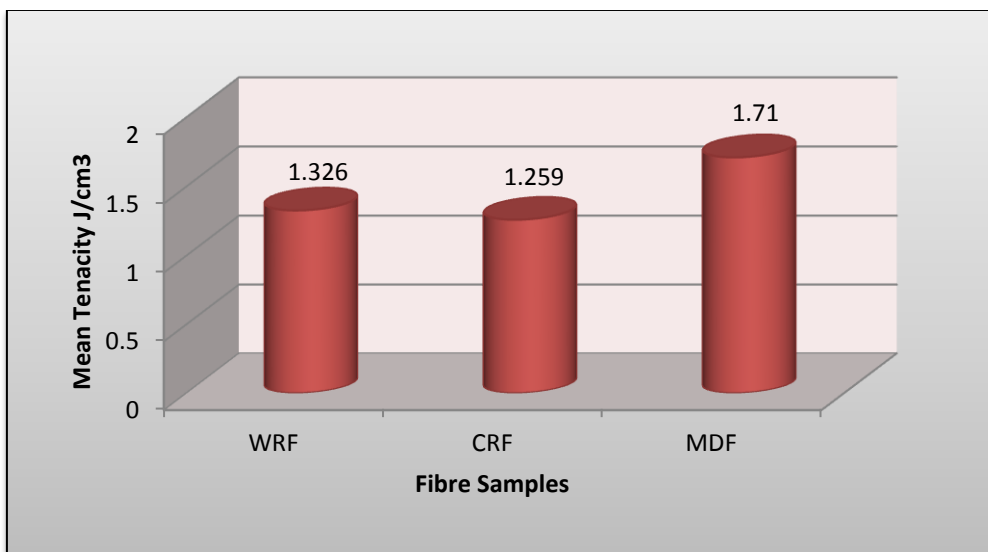
It is clear from the Table XI and Figure 9, the sample MDF shows an increase in work to rupture as 103.22 followed by sample WRF with its mean value as 59.39, whereas a decrease in work to rupture is seen in sample CRF with 55.81. The reason for an increase of work to rupture in the sample MDF might be due to breaking extension and the decrease in work to rupture is seen in sample CRF due to the low breaking extension. Thereby it is evident that work to rupture is directly proportional to strength of sample. The result of work to rupture shows the 1 percent significant level.

Hence it could be concluded that the result of the specific work to rupture had its minimum value in MDF sample.

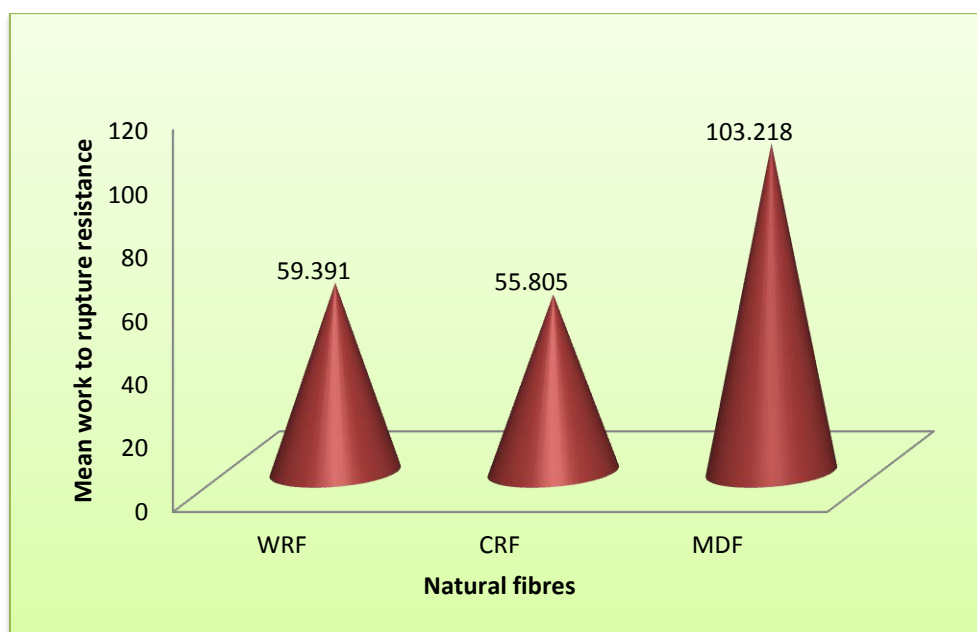
#### 4.2.6. TGA analysis and DTG analysis



**Figure- 10**  
**TGA and DTG analysis**



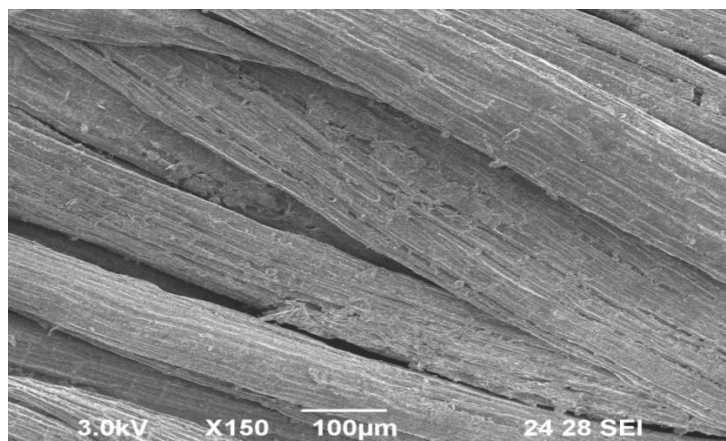
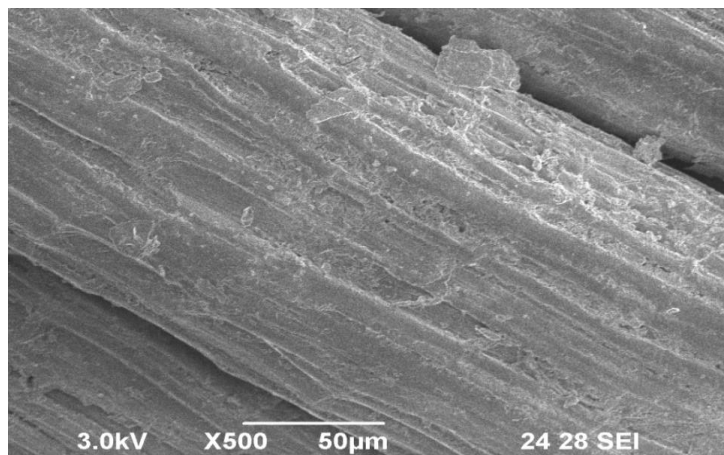
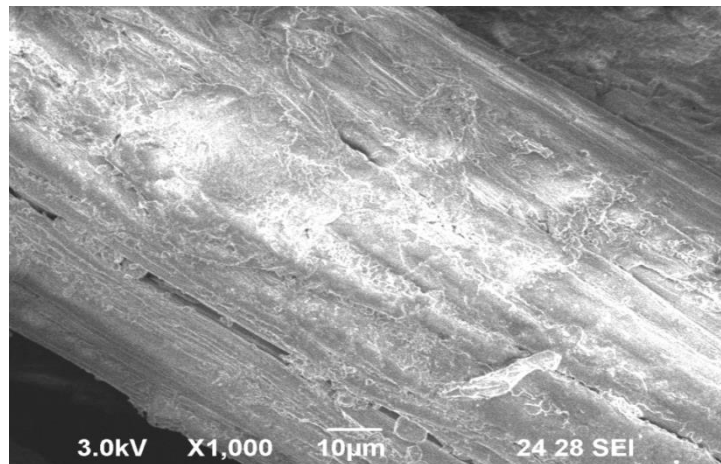
**Figure- 8**  
**Breaking tenacity of fibre**



**Figure- 9**  
**Work to rupture resistance of fibre**

#### 4.2.7. SEM analysis

The extracted fibre using mechanical decorticator was given for SEM analysis and the report shows that the size of the fibre ranged from 10  $\mu\text{m}$  to 100  $\mu\text{m}$  under 1000X, 500X, 150X magnification. The fibre was viewed using a Scanning Electron Microscope with 3.0 kv electron beam was shown in below.



### 4.3. Moisture content test for chopped fibres

Moisture content of the *Cyperus pangorei* (korai grass) in before and after drying was evaluated and presented in Table XII.

**Table-XII**  
**Moisture content of fibre**

<b>S.NO</b>	<b>Before drying wt (in grams)</b>	<b>Time</b>	<b>After drying wt (in grams)</b>
1.	100	1 hour later	99.25
2.	100	2 hour later	98.75
3.	100	3 hour later	98.13
4.	100	4 hour later	96.66

The moisture content test as presented in Table XII denotes that the fibres show a considerable decrease in weight with respect to their dryness and time. As drying time increases, the weight shows considerable reduction. It is evident that the fibre moisture content of the reduces by 99.25, 98.75, 98.13 and 96.66 at 1 hour, 2 hour, 3 hour and 4 hours drying time respectively with respect to its original weight which was 100g before drying.

Hence it could be concluded that the maximum time presents the maximum reduction of moisture and weight reduction.

#### 4.4. Evaluation of composites

##### 4.4.1. Tensile strength of biocomposites

The strength of the biocomposites material and its analysis of variance with respect to samples WRF/PP, CRF/PP and MDF/PP is depicted in Table XIII and Figure 11.

**Table-XIII**  
**Tensile strength of biocomposites**

S. No	Samples	Mean strength (MPa)	Standard deviation	"F" ratio
1.	WRF/PP	24.70	0.2000	3610.06*
2.	CRF/PP	30.01	0.4494	
3.	MDF/PP	30.27	0.0200	

\*- 1% significance level

From the Figure 11 and Table XIII it is perceptible that the sample MDF/PP, CRF/PP and WRF/PP shows their mean strength as 30.27, 30.01 and 24.7 MPa respectively. The highest strength is observed in samples MDF/PP and the least strength is seen in water retted fibre reinforced PP sample. From these values it is determined that the mechanically decorticated sample show good tensile strength. Apart from these comparisons, the MDF sample is also compared with the finding of Karnani *et al.*, (1997) to the strength of raw PP and kenaf fibre reinforced PP, MDF/PP sample show the maximum strength than raw PP and kenaf reinforced PP whose values were 28.4 and 26.9 MPa. This shows that reinforcement of korai grass fibres with PP show high strength. The reason behind this may be due to its morphology, amount of PP and high matrix ductility. The statistical analysis shows that there is one percent significance level.

Finally, it is understood that the mechanically decorticated fibre exhibit the maximum strength.

#### 4.4.2. Elongation of biocomposites

The analysis of variance and various biocomposites of WRF/PP, CRF/PP and MDF/PP elongation is given in Table XIV and Figure 12.

**Table- XIV**  
**Elongation of biocomposites**

S. No	Samples	Mean elongation (%)	Standard deviation	"F" ratio
1.	WRF/PP	3.81	0.020	348.942*
2.	CRF/PP	4.03	0.020	
3.	MDF/PP	4.09	0.012	

\*- 1% significance level

The elongation of the Biocomposite material reinforced with PP in WRF, CRF and MDF shows 3.81, 4.03 and 4.09 as their elongation value. From the results given in Table XIV and Figure 12, it is evident that the elongation of MDF/PP had increased in value when compared to CRF/PP and WRF/PP, whereas the sample MDF/PP showed a decrease in elongation when compared to raw PP and kenaf reinforced PP. The values of MDF/PP, kenaf/pp and raw PP were 4.09, 5.2 and 9.5 respectively with the maximum elongation seen in raw PP as reported by Karnani *et al.*, 1997.

Hence it could be concluded that though MDF/PP showed a decrease in elongation when compared to kenaf/PP and original PP, the mechanically decorticated sample showed increase in elongation among WRF/PP and CRF/PP. However the 'F' value 348.942 shows significant difference at 1 per cent between the biocomposite samples.

#### 4.4.3. Impact strength of biocomposites

The impact strength of original PP, kenaf/ PP, MDF/PP, CRF/PP and WRF/PP are represented in Table XV and Figure 13.

It is clear that the mean impact strength of the sample WRF/PP was found to be 38.80 J/m whereas the samples CRF/PP and MDF/PP showed a slight increase in strength when compared to WRF /PP.

**Table-XV**  
**Impact Strength of biocomposites**

S. No	Samples	Mean Impact Strength (J/m)	Standard deviation	“F” ratio
1.	WRF/PP	38.80	0.2000	535.038*
2.	CRF/PP	41.30	0.2000	
3.	MDF/PP	42.03	0.02012	

\*- 1% significance level

The strength of the CRF/PP and MDF/PP was identified to be 41.3 and 42.03 J/m, among which MDF/PP showed the maximum impact strength. This is also found to be good in comparison with kenaf/PP results showing not much difference. The Impact Strength of kenaf/PP was found to be 43.8 MPa. The Table also shows the ‘F’ value and they are significant at 1 per cent level.

#### 4.4.4. Density of biocomposites

Table XVI and Figure 14 demonstrate the density of MDF/PP, CRF/PP and WRF/PP samples.

**Table- XVI**  
**Density of biocomposites**

S. No	Samples	Mean Density(J/cm <sup>3</sup> )	Standard deviation	“F” ratio
1.	WRF/PP	1.8260	0.002	17103.75*
2.	CRF/PP	1.769	0.002	
3.	MDF/PP	1.994	0.002	

\*- 1% significance level

The results of density shown in Table XVI and Figure 14 suggest that the sample MDF/PP show greater density when compared to WRF/PP and CRF/PP samples. The density values of WRF/PP, CRF/PP and MDF/PP are found to be 1.826, 1.769 and 1.994 J/cm<sup>3</sup> respectively. The increase in density might be due to the fibre extraction process. This increase in density of the MDF/PP sample is found to be higher when compared to kenaf/PP. Significant at 1 percent level was observed when density of composites are compared.

#### 4.4.5. Hardness of biocomposites

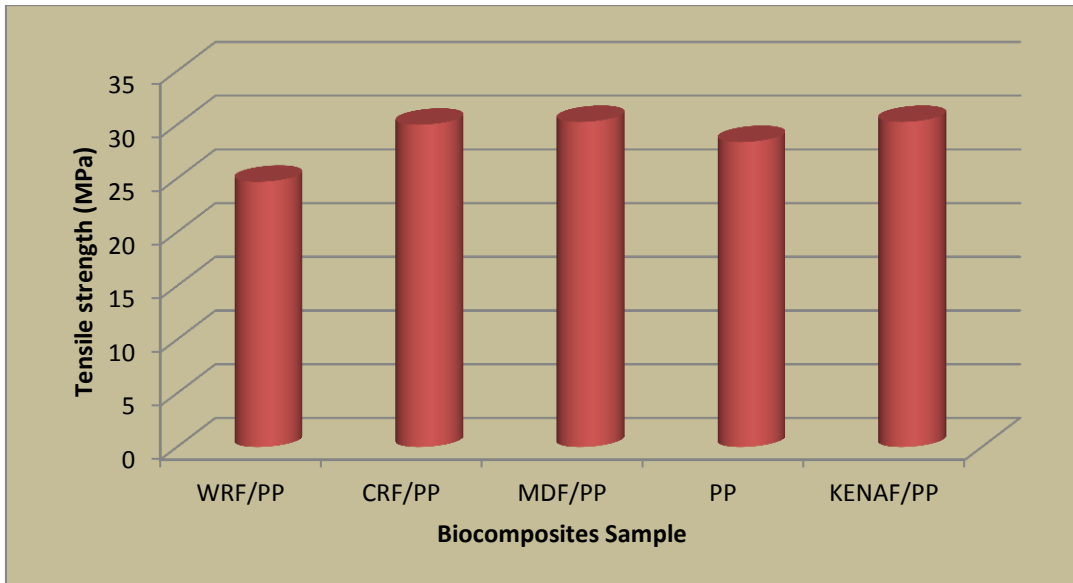
The hardness of WRF/PP, CRF/PP and MDF/PP is given in Table XVII and Figure 15.

**Table-XVII**  
**Hardness of biocomposites**

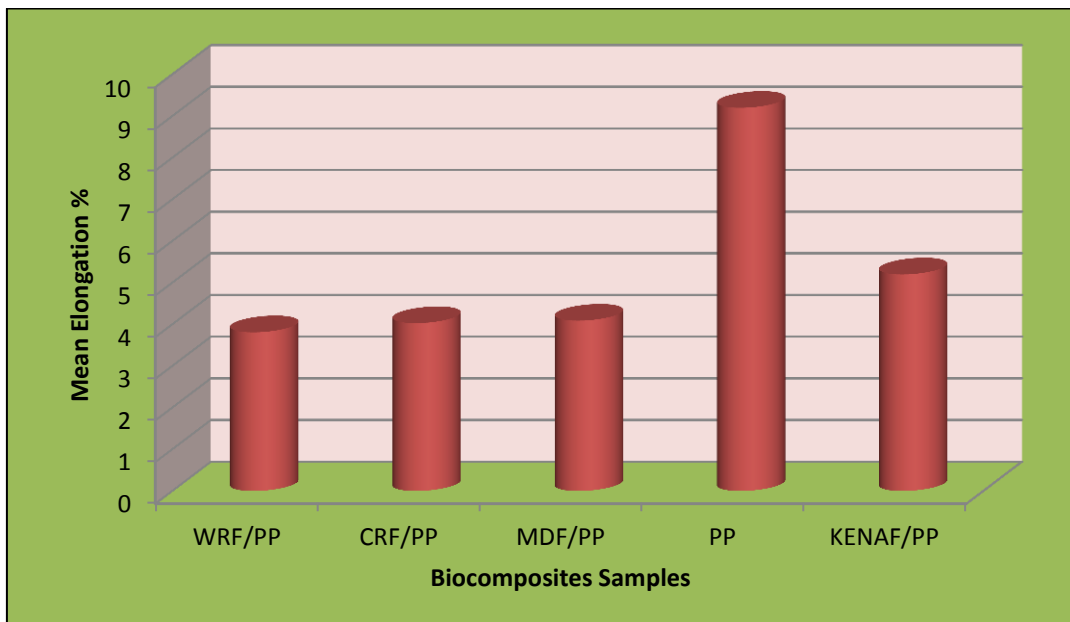
<b>S. No</b>	<b>Samples</b>	<b>Mean Hardness Shore D</b>	<b>Standard deviation</b>	<b>“F” ratio</b>
<b>1.</b>	WRF/PP	73.21	0.020	37040.00*
<b>2.</b>	CRF/PP	74.81	0.020	
<b>3.</b>	MDF/PP	76.65	0.020	

\*- 1% significance level

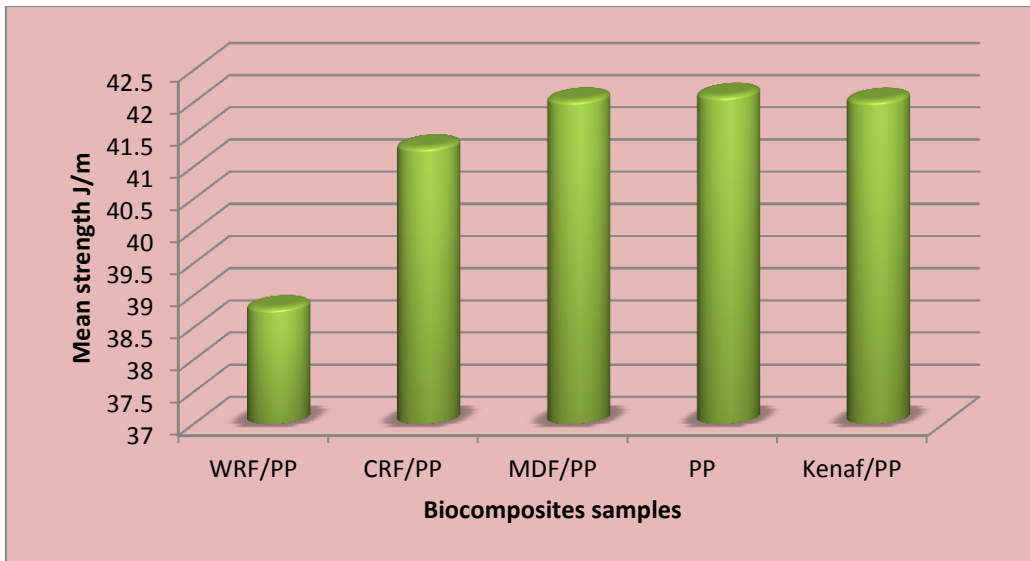
The Table XVII and Figure 15 reveal that the sample MDF/PP and CRF show the maximum mean hardness value on account with WRF/PP and CFR/PP with MDF/PP. When considering the mean values, 73.21 were seen in WRF/PP, 74.81 in CRF/PP and 76.65 in MDF/ PP at 1 per cent level. The samples are significant at one percent level. Hence, it could be concluded that the sample that is mechanically decorticated and reinforced with PP has the highest hardness value.



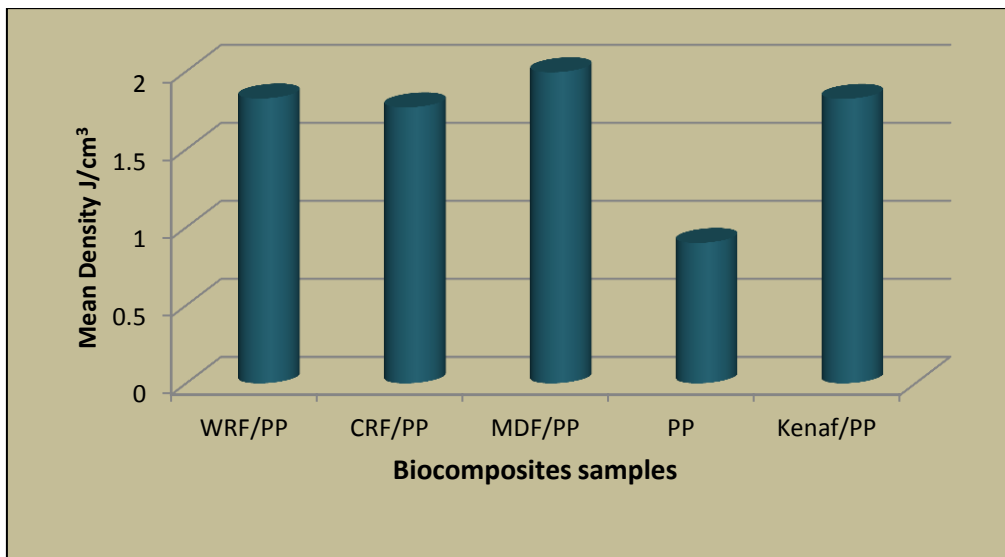
**Figure- 11**  
**Tensile strength of biocomposites**



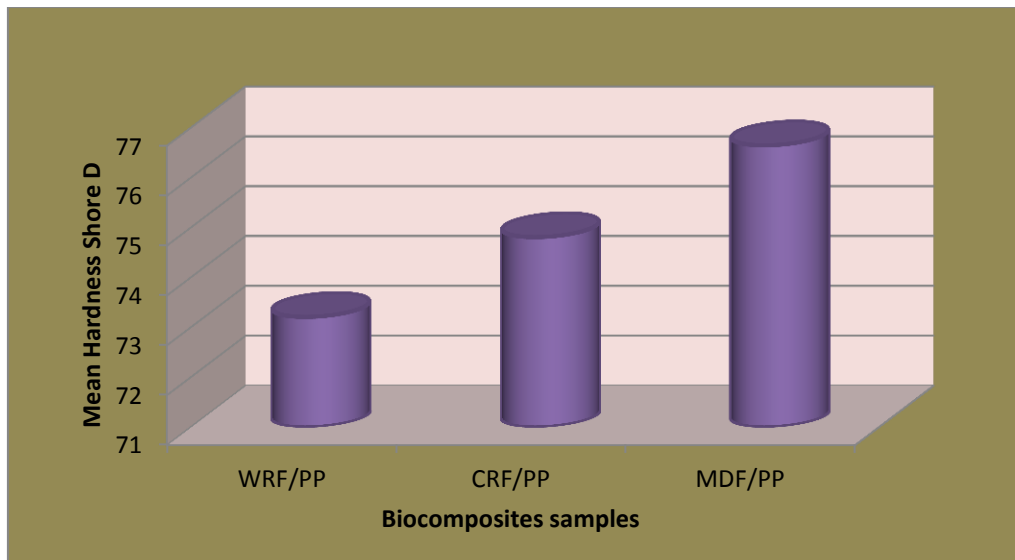
**Figure- 12**  
**Elongation of biocomposites**



**Figure- 13**  
**Impact strength of biocomposites**



**Figure- 14**  
**Density of biocomposites**



**Figure- 15**  
**Hardness of biocomposites**

## 5. SUMMARY AND CONCLUSION

The persistence of plastics in the environment, the shortage of landfill space, concerns over emissions during incineration entrapment and ingestion hazards from these materials have spurred efforts to develop biodegradable materials. Most of today's synthetic polymers are produced from petrochemicals and are not biodegradable. In order to be competitive, biodegradable polymers must have the desirable properties as obtained in conventional plastics and have offered scientists a possible solution to waste disposal problems associated with biofibres.

Natural fibres also favor the 'go green' technology in composite fabrication system due to their biodegradable and renewable properties. The prominent advantage of natural fibres includes acceptable tensile properties, low cost, high toughness, good thermal properties, low densities and non abrasive nature, high filling level possible, low energy consumption and high specific properties. Within the past few years, there has been a dramatic increase in the use of natural fibres for composites.

The concept of bio-based materials has now become key importance due to the need to preserve our environment. Biocomposites are composite material comprising one or more phases derived from a biological region which means they are the combination of natural fibres or biofibres with polymer matrices from both of the renewable and nonrenewable resources.

Polypropylene plays an important place primarily due to its recyclability, low cost, high thermal stability and good price/performance ratio. The important feature of composite materials is that they can be designed and tailored to meet different requirements. Injection molding method is normally used for high volume and low cost component manufacturing.

Therefore investigator has carried out the study to utilize "***Cyperus pangorei***-**A Natural Fibre for Biocomposites**" with the objectives as follows;

- To extract the natural fibre from cyperus pangorei and examine its properties.
- To convert the extracted fibre into BioComposites.
- To evaluate and study the effectiveness of BioComposites for automobile industrial applications.

*Cyperus pangorei* was selected as a bio fibre for the study. The *cyperus pangorei* (korai grass) was extracted by using different methods such as water retting, dew retting, chemical retting and mechanical decortications.

The biocomposites material was prepared by using the *cyperus pangorei* with the reinforcement of thermoplastic polypropylene matrix as per the procedure given below:

The *cyperus pangorei* stems were extracted by using water retting, dew retting, chemical retting and mechanical decortications method. Water retting was done by immersing the full length of *cyperus pangorei* (korai grass) about 10 cm and soaked into the open water tanks with the size of 5 feet length, 4 feet width and 2 feet in depth. After 4 weeks the stems were taken out and fibres were separated. Dew retting was carried out by drying the stems under the conditions of moderate humidity, warmth and was spread evenly in a grassy field. After deterioration of stems for 15 days it was removed from the field and the fibres were separated by hackling the stems. Chemical retting was done by treating the stems with NaOH for 6-8 hours. Then the fibres were combed out and dried under the shade. Mechanical decortication was done by using decorticator. The green stems were fed into the machine through feed table and the stems were decorticated.

The extracted length of the fibre by using various methods of extraction, were chopped into short lengths of 4 mm approximately to ensure an easy blending. Prior to compounding the chopped fibres were dried in an oven at 60°C for 4 hours to reduce the moisture present in the fibres.

The *Cyperus pangorei* (korai grass) fibres and matrix of PP granules were mixed and fed in twin extruder device. By using this, the pellets were formulated. Both materials were added to the machine at the same time with a weight ratio of 30:70 (Grass fibre: Polypropylene). The polymer and fibre mixture was compounded at a maximum temperature of 190°C which is above the melting point of thermoplastic matrix for 15 minutes and a screw speed of 100 rpm in the twin screw extruder. In the die zone the 5mm gauge circular die was fitted to get the circular pellets. The strands were dried and subsequently pelletized. The screw diameter was 25 mm and the screw L/D ratio was 48:1.

All the pelletized formulations were injection molded to get the BioComposites material. The pellets were fed by using gravimetric force. To avoid the thermal degradation, the temperatures was set in the three main zones ranging from 160-220°C. The melted material was mixed into the screw. From the feed zone the material was passed to die zone through a nozzle. The injection pressure was 60MPa and the cycle time was 30 seconds. The time intervals for the packing and cooling stages were 30 and 25 seconds respectively. The specimens were prepared. The treated fibres were subjected to various tests such as mechanical properties, TGA analysis and SEM analysis.

## Findings

- The water retted fibre, chemical retted fibre and mechanical decorticated fibre samples were evaluated subjectively and objectively. The mechanical decorticated fibre sample was rated as good in general appearance. The brightness and texture also rated as good. The chemically retted fibre sample was rated as excellent in brightness.
- The length of the fibres were obtained depends upon the method of extraction used. And the fibres sample has no crimp and it is burnt like paper and it remains ash after burned. The fibre samples were soluble in sulfuric acid (70% at 40°C temperature) and in NaOH (10% at 40°C) resulting in the half soluble of fibre and high colour effectiveness.
- The tensile strength of the mechanically decorticated fibre is higher because of the absence of chemicals and microorganisms used. The mechanically decorticated fibre sample recorded the highest increase in tensile strength by 277.20 MPa. But compared to other natural fibres it shows the almost nearest value in strength.
- The elongation of fibre is higher in the mechanically decorticated fibre sample. The mechanical decorticated fibres elongation is higher by 1.0450 followed by the sample WRF and CRF with the values of 0.7190 and 0.7160 respectively. Compared to other natural fibres korai grass fibre sample has the almost similar elongation percentage.
- The mechanically decorticated fibre sample is increased in tenacity and work to rupture with the mean value of 1.71 and 103.22 respectively. And the water retted

fibre and chemical retted fibre also exhibit the nearest value to mechanically decorticated fibre in both tenacity and work to rupture.

- From the TGA analysis, it is observed that the fibre could withstand the temperature of about 300°C. In the SEM analysis the morphology of the fibre was observed. The report shows that the size of the fibre ranged from 10 to 100 µm under 1000X, 500X, 150X magnification.
- The chopped fibres are observed for its moisture content. It is placed in the oven at 60°C for 4 hours. The weight of the fibre is decreased after 4 hours with the removal of moisture by more or less 4 percent.
- The mechanically decorticated fibre reinforced polypropylene composite is increased in tensile strength by the mean value of 30.27 compared to water retted fibre reinforced polypropylene composite and chemically retted fibre reinforced polypropylene composite. This is due to the lowered strength of fibre because of the use of microorganisms and chemicals for the extraction.
- The elongation of mechanically decorticated fibre reinforced polypropylene sample has exhibited 4.09 percent increase, whereas the water retted fibre reinforced polypropylene (3.81) and chemical retted fibre reinforced polypropylene (4.03) shows the less value when compared to mechanical decorticated fibre.
- The mechanically decorticated fibre reinforced polypropylene composite is increased in impact strength with a mean value of 42.03 compared to water retted fibre reinforced polypropylene composite (38.80) and chemical retted fibre reinforced polypropylene composite (41.30).
- The mechanical decorticated fibres sample has shown increase in its hardness by the mean value of 1.994 and the high density of these fibres is observed.

## **CONCLUSION**

The research describe that Biocomposites could be fabricated with PP by various extraction methods from *Cyperus pangorei* (korai grass). The results based on the mechanical properties of korai grass biocomposites shows only a slight difference with other natural fibre biocomposites. Hence it could be concluded that the selected *Cyperus pangorei* fibre can be effectively used for composite preparation.

## **Recommendations**

- Varied lengths of fibre may be tried in composite preparation.
- Coupling agents can be employed to enhance the composite properties.

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## **WEBSITES**

<http://www.industreecrafts.org>

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## APPENDIX- I

### VISUAL EVALUATION

S.No	Samples	General appearance			Texture			Brilliancy of colour		
		E	G	F	S	M	C	H	M	L
1	WRF									
2	DRF									
3	CRF									
4	MDF									

E- Excellent, G-Good, F-Fair, S-Soft, M-Medium, C-Coarse, H-High, M-Medium, L-Low.

## APPENDIX II

### FIBRE AND FABRICATED SAMPLES



Water Retted Fibre



Chemical Retted Fibre



Mechanical decorticated  
Fibre



Fabricated Specimen