

## DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “**Tensile Properties and Water Absorption of Wood Sawdust Filled Polypropylene Composites**”. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or University.

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## LIST OF ABBREVIATIONS

PP	Polypropylene
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier Transform Infrared Spectroscopy
FFPP	Fiber Filled Polypropylene
T	Treated
UT	Untreated
NFRC	Natural Fiber Reinforced Composite
TS	Tensile Strength
TM	Tensile Modulus
FS	Flexural Strength
FM	Flexural Modulus
ASTM	American Society for Testing and Materials
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PVC	Polyvinylchloride
PS	Polystyrene
WS	Wood Sawdust
ES	Egg Shell
KF	Kenaf
CS	Coconut Shell

## LIST OF SYMBOLS

Wt%	Weight percent
%	Percentage
°C	Degree Celcius
phr	Part per Hundred Resin
MPa	Mega Pascal
GPa	Giga Pascal
hrs	hours
mm	Millimeter
μm	Micrometer

# **SIFAT TEGANGAN DAN PENYERAPAN AIR KOMPOSIT POLIPROPOLENA TERISI HABUK KAYU**

## **ABSTRAK**

Keupayaan biodegradasi gentian semulajadi adalah salah satu aspek yang paling menjanjikan dan dikaitkan dengan penggunaannya dalam bahan polimer. Tujuan projek ini adalah untuk membandingkan prestasi habuk kayu yang dirawat dan tidak dirawat dipenuhi PP komposit dengan pemuatan gentian yang berbeza iaitu 2.5% berat, 5% berat, 7.5% berat dan 10% berat. Perbandingan di antara sifat komposit habuk kayu dengan komposit pelbagai jenis serat semulajadi dan pengisi turut dilakukan. Habuk kayu telah dirawat dengan larutan NaOH. Komposit habuk kayu diadun dengan menggunakan pencampur dalaman Thermo Haake Polydrive yang diikuti oleh acuan mampatan. Ciri-ciri tegangan, morfologi, analisis kumpulan berfungsi kimia dan penyerapan air komposit dianalisa. Secara umum, komposit habuk kayu yang dirawat menunjukkan 7.1% dan 4.1% peningkatan masing-masing dalam kekuatan tegangan dan modulus tegangan pada gentian 2.5% berat dan 7.5% berat dibanding dengan komposit habuk kayu yang tidak dirawat. Berdasarkan pemerhatian morfologi, permukaan kasar yang wujud oleh rawatan alkali meningkatkan luas permukaan gentian dan matriks dengan meningkatkan ikatan antarafasa. Tambahan pula, komposit habuk kayu dirawat menunjukkan penyerapan air sebanyak 7.8% lebih rendah berbanding dengan komposit habuk kayu tidak dirawat. Selain itu, sifat tegangan seperti kekuatan tegangan dan modulus tegangan dari pelbagai jenis gentian semulajadi and pengisi telah dibandingkan. Secara umum, komposit PP dengan tempurung kelapa menunjukkan sifat tegangan tertinggi berbanding komposit dengan habuk kayu, gentian kenaf dan kulit telur. Sebagai kesimpulan, komposit habuk kayu yang dirawat menunjukkan kesan positif terhadap sifat komposit PP berbanding komposit habuk kayu yang tidak dirawat.

# **TENSILE PROPERTIES AND WATER ABSORPTION OF WOOD SAWDUST FILLED POLYPROPYLENE COMPOSITES**

## **ABSTRACT**

The biodegradability of natural fiber is one of the most promising aspects that related to their incorporation in polymeric materials. The aim of this project is to compare the performance of treated and untreated wood sawdust filled PP composites with different fiber loading which are 2.5 wt%, 5 wt%, 7.5 wt% and 10 wt%. Comparison on the properties of wood sawdust composites with various types of natural fiber and filler composites was carried out. The wood sawdust was treated with NaOH solution. Sawdust filled PP composites were compounded by using Thermo Haake Polydrive internal mixer followed by compression molding. The tensile properties, morphology, chemical functional group analysis and water absorption of composites were analysed. In general, the treated sawdust filled PP composites exhibit 7.1% and 4.1% improvement in tensile strength and tensile modulus at 2.5 wt% and 7.5 wt%, respectively than those untreated sawdust filled PP. Based on the morphology observation, rougher surface introduced by the alkaline treatment increases the surface area of contact of the fiber and matrix by improving the interfacial bonding. Furthermore, treated sawdust filled PP composites show 7.8% lower water absorption as compared with untreated sawdust filled PP composites. Besides, the tensile properties such as tensile strength and Young's modulus of various types of natural fibers were compared. In general, coconut shell shows the highest tensile properties compared to those composites with wood sawdust, kenaf fiber and egg shell filled PP composites. In conclusion, treated sawdust composites exhibit a positive effect on PP composites properties compared to the untreated sawdust composites.

# CHAPTER 1

## INTRODUCTION

### 1.1 Research Background

Natural fiber Reinforced composites (NFRC) have been undergoing a significant transformation over the past few decades. These materials were developed tailored for specific needs and applications by combination of natural fibers in a polymer matrix. In recent years, natural fiber filled composites is replacing the synthetic fiber filled composites due to the properties of low cost, renewability, sustainability and low abrasive nature. There has been an increasing interest in cellulose based composite materials due to their availability and biodegradability (Kaur et al., 2018). Table 1.1 shows the advantages and disadvantages of NFRC.

Table 1.1: Advantages and disadvantages of NFRC (Pickering et al., 2016)

Advantages	Disadvantages
<ul style="list-style-type: none"><li>• Low density</li></ul>	<ul style="list-style-type: none"><li>• Lower durability</li></ul>
<ul style="list-style-type: none"><li>• High specific strength and stiffness</li></ul>	<ul style="list-style-type: none"><li>• High moisture absorption, which results in swelling</li></ul>
<ul style="list-style-type: none"><li>• Low cost</li></ul>	<ul style="list-style-type: none"><li>• Lower processing temperatures limiting matrix options</li></ul>
<ul style="list-style-type: none"><li>• Production requires little energy and involves CO<sub>2</sub> absorption</li></ul>	<ul style="list-style-type: none"><li>• Greater variability of properties</li></ul>
<ul style="list-style-type: none"><li>• Less abrasive damage to processing equipment</li></ul>	<ul style="list-style-type: none"><li>• Lower strength</li></ul>
<ul style="list-style-type: none"><li>• Low hazard manufacturing process</li></ul>	
<ul style="list-style-type: none"><li>• Low toxic fumes emitted when subject to heat</li></ul>	

Natural fiber consists mainly of cellulose, lignin and hemicellulose. Cellulose is interlocked with the lignin and hemicellulose. Therefore, natural fibers behave as hydrophilic characteristic due to the presence of hydroxyl and carboxylic groups in the network structure of natural fiber where this characteristic limited their performance as reinforcing agent. Thus, before natural fiber being used as reinforcing agent, a chemical treatment is required in order to improve or meet the desired properties for any NFRC application. Chemical treatment is needed to reduce the hydrophilic characteristic of natural fiber and to improve the wettability of the natural fiber to achieve better properties. According to Alvira et al. (2010) and Kumar and Sharma (2017), an effective chemical treatment should meet the following requirements:

- Deconstructing the 3-D structure of lignocellulose and break down the semi-crystalline cellulose and hemicellulose.
- Avoid the reduction in size of the particles
- Give highly digestible treated solid
- Avoid or minimize the formation of degradation products
- Cost effective
- Avoid the formation of toxic byproducts during the process
- Minimize the energy demands

Most of the chemical treatment is used to break up the complex network structure and to remove lignin and hemicellulose and only left behind cellulose for further processing. After the natural fiber is treated, when the cellulose is integrated into commodity plastic, it subsequently provided significant enhancement on thermal resistance, mechanical properties as well as environmental friendly properties. By compounding a small amount of cellulose into commodity plastic can be tailored significant effort on many areas of research according to Ummartyotin and Pechyen



(2016). Furthermore, cellulose also gives numerous advantages which are specific design, low cost and effective processing as well as commercially available for mass production due to cellulose is one of the most abundant naturally occurring composite.

## **1.2 Problem Statement**

In recent years, with the shortage of petrochemical resources and the deterioration of the environment due to greenhouse gas emissions from fossil fuels combustion stimulated green and sustainable resources have become a social hot spot such as biomass. Moreover, petroleum-based film used for food packaging materials are non-biodegradable, diminishing oil resources, environmental apprehensions for the disposal and health or toxicity issues.

Cellulose, as the world's most abundant biomass resource, has attracted attention due to its advantages of renewable and green cleaning. The dispersion of cellulose with enormous specific surface area and specific ratio into polymer matrix is a new technique to improve or modify mechanical, thermal and barrier properties such as water vapour permeability of the composite. Therefore, the use of polypropylene (PP) filled with cellulose can deliver greener materials for selected application. PP is oil-based materials, which are not biodegradable, but it can be recycled. Furthermore, it exhibits a hydrophobic behaviour being able to work under humid condition. Therefore, PP can be used successfully to prepare the composite.

There is large quantity of biomass generated by wood industries as sawdust. To obtain economical products with good mechanical properties, this research project is conducted to develop composite materials. Polypropylene-sawdust composites are low cost materials and may contribute to solving environmental problems considering that polypropylene PP is recyclable and has low price and favorable mechanical properties while sawdust is cheap, highly available, biodegradable and renewable.

### **1.3 Objective**

- To investigate the effect of wood sawdust loading on the properties of polypropylene composite.
- To compare the difference in properties of treated wood sawdust filled PP and untreated wood sawdust filled PP.
- To compare the properties of wood sawdust filled PP composites with kenaf, coconut shell and egg shell filled PP composites.

### **1.4 Thesis Outline**

Chapter 1: Discuss on the introduction of dissertation including background of natural fiber filled polymer, problem statement, objectives of this study and the scope of this project.

Chapter 2: Discuss on the overview survey of literature on the natural fiber filled polymer, the type of natural fiber, the type of polymer, chemical treatment of natural fiber, and their role and properties in reference to widely relevant to the previous works or research that are related to this project.

Chapter 3: Discuss about the raw materials being used in this project. The methodology of this project and the characterization method used in this project also discussed in this chapter.

Chapter 4: Discuss and analysed the results and findings of the experimental works done and integrating the information on the usefulness of filling method in this study.

Chapter 5: Discuss on the conclusion for this project and the recommendation for future study.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Food packaging has evolved and developed over thousands of years. Packaging provides essential protection from the environment and from chemical and physical challenges such as spoilage microorganisms, chemical contaminants, oxygen, moisture, light, external force and so on, thereby playing a crucial role in protecting the quality and safety of food products.

Food packaging is not only used as a container but also acts as a protective barrier against permeation of water vapour, oxygen, carbon dioxide and other volatile compounds such as flavours and contaminate in addition to the basic properties of packaging materials (Rhim et al., 2013) as shown in Figure 2.1.

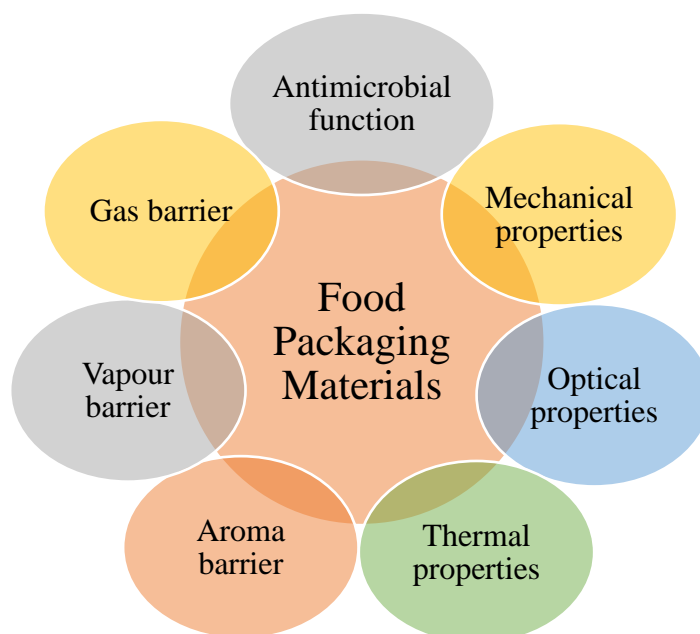


Figure 2.1: General properties required for food packaging materials. (Rhim et al., 2013)

In food packaging industries, the petroleum-based plastic materials have been widely used since the middle of the twenties century. This is because they are low cost

and convenient to use with good processing property, good aesthetic quality and excellent physico-chemical properties (Rhim et al., 2013). However, the synthetic plastic packaging materials causes a serious environmental problem since they are not easily degraded in the environment after use. Therefore, there are increasing concern over environmental burdens and exhausting natural resources caused by non-biodegradable plastic packaging materials and food safety caused on increased demand for biodegradable packaging materials or recyclable packaging materials as the alternative to the synthetic plastic packaging materials (Rhim et al., 2013). Recently, interest in natural fiber filled polymer matrix is growing for many reason including their potential to replace synthetic fiber filled plastic, the use of greener materials (Pickering et al., 2016) and further enhancement of the properties of the application. NFRC are renewable, cheap, completely or partially recyclable, and biodegradable. The NFRC are environmental friendly, and can be used in transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling panelling, partition boards), packaging, consumer products, etc (Chandramohan and Marimuthu, 2011).

## **2.2 Natural Fiber**

Fibers form a class of hair-like materials in the form of continuous filaments or in discrete elongated pieces, like pieces of thread. They can be spun into filaments, thread, or rope (Chandramohan and Marimuthu, 2011). Natural fibre can be further defined as an agglomeration of cells in which the diameter is negligible in comparison with the length (The Editors of Encyclopaedia Britannica, 2016). There are 2 types of fiber which are natural fiber and synthetic fiber. When is a fiber “natural”? A fiber is considered as natural fiber when it does not include any modern man-made artificial and synthetic fibers such as rayon, nylon, acrylic and polyester (Adam, 2009).

### **2.2.1 Classification of natural fiber**

Natural fibers can be classified according to their origin which are plant fibers, animal fibers and mineral fibers. Figure 2.2 shows the classification of natural fibers and the examples of each class of natural fibers. According to Akil et al. (2011), the most popular natural fibers are plant fibers. Plant fibers can be obtained from the various parts of the plants which are bast or stem, leaf, seed or fruit, grass and wood. Plant fibers are nature designed composite materials and they are basically comprised of a rigid, crystalline cellulose microfibril reinforced amorphous lignin, and/or hemicellulose matrix (Akil et al., 2011). Chemically, all plants fibers containing mainly of cellulose and also varying amount of other substances such as hemicellulose, lignin, pectins, and waxes that must be removed or reduced by processing (The Editors of Encyclopaedia Britannica, 2016) before they are being used for any application. Meanwhile, animal fibers are generally made up of proteins. For examples silk, wool, angora, mohair and alpaca (New World Encyclopedia contributors, 2014). For mineral sources fibers, they can be obtained in their naturally occurring or by undergoing some modification.

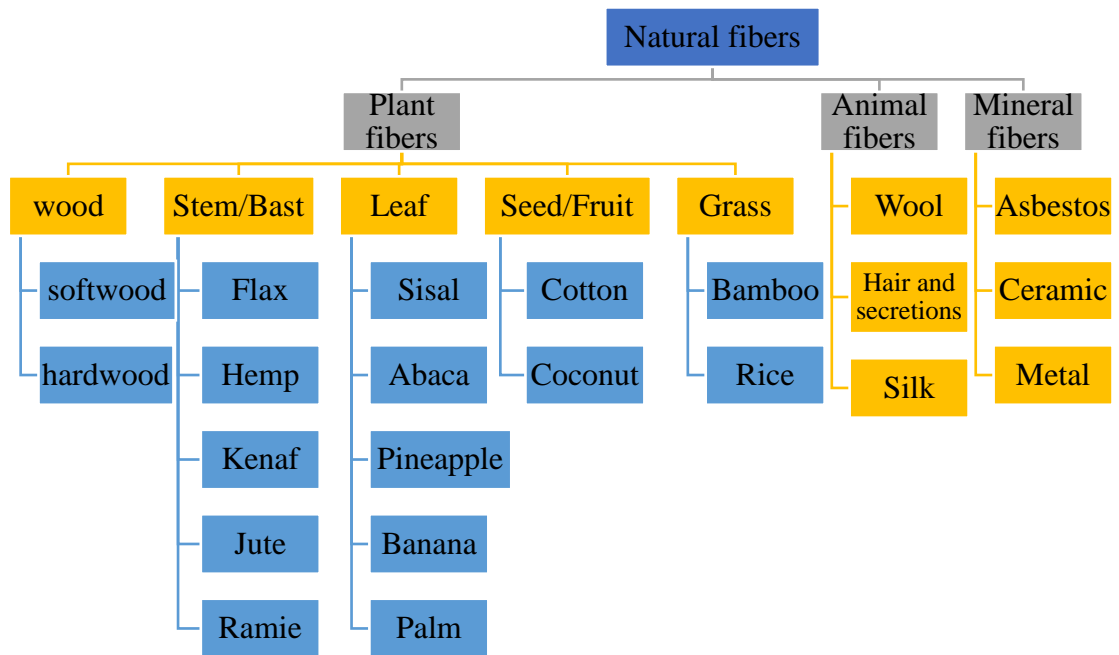


Figure 2.2: Classification of natural fibers and examples for each class. (New World Encyclopedia contributors, 2014) (Chandramohan and Marimuthu, 2011)

Cellulose is the main constituent for any plant fiber (Akil et al., 2011). It is a natural homopolymer (polysaccharide), where a large number of glucose units combines to form a cellulose polymer molecule, which depends on their chain length and rate of polymerization (Theivasanthi et al., 2017). The structure of cellulose is  $\beta$ -(1  $\rightarrow$  4) - glycosidic linkages (Akil et al., 2011) as shown in Figure 1.2.

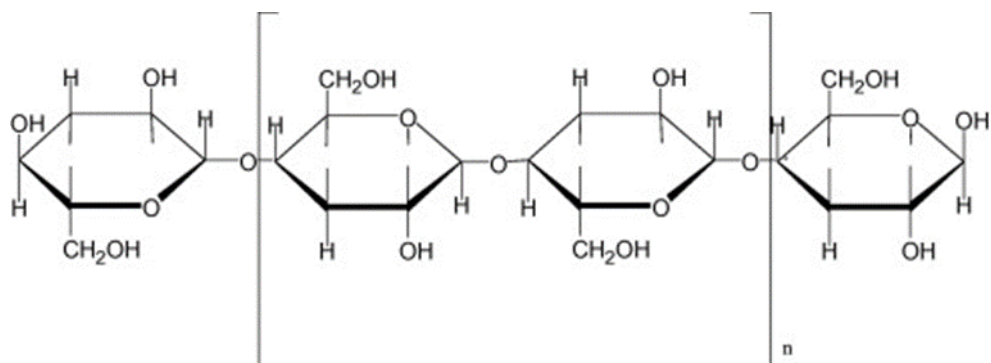


Figure 2.3: Chemical structure of cellulose

Cellulose as the main chemical composition of lignocellulose is currently the main raw material of pulp and paper industry, textile industry, fiber chemical industry

and biomass energy. In lignocellulose, hemicellulose and lignin are used as "adhesives" and "fillers" to protect the fibers. However, cellulose is still limited in particular categories of food. The alteration of food quality is based on fresh food, dry food and semi-dry food. To serve on the variation of food quality, the design on food packaging should be extremely focused by maintaining the quality of food with higher efficiency (Ummartyotin and Pechyen, 2016). Plastic based composite and by reinforcing a small amount of cellulose is one of the effective routes that solve the limitation stated above (Ummartyotin and Pechyen, 2016). It is important to note that cellulose manifested many benefits due to high porosity, high chemical and thermal resistance, cost effectiveness, ease of processing as well as availability.

### **2.2.2 Chemical Treatment of Natural Fiber**

In spite of the utilization and application of NFRCs are increasing, their performance is limited due to the presence of hydroxyl and carboxylic groups in the structure of natural cellulosic fibers resulting a hydrophilic characteristic (Jaya et al., 2016). When the fibers are filled in hydrophobic matrices, i.e. polymers, the resulting composite may reduce their potential as reinforcing agents ( Malenab et al., 2017) due to the hydrophilic nature hinders the effective reaction with the matrix. Furthermore, pectin and waxy substances cover the reactive functional groups of the fibre and thus they act as a barrier to interlock with the matrix (Kabir et al., 2012). Therefore, some modifications are considered to optimize the interface of fibers or reduce the hydrophilic tendency and thus improve wettability of the natural fiber with the matrix (Kabir et al., 2012). These may activate the hydroxyl groups or introduce new elements or parts that can effectively interlock with the matrix. As a result, the composite with better desired properties can be achieved. Figure 2.3 shows the schematic of the role of treatment of natural fiber.

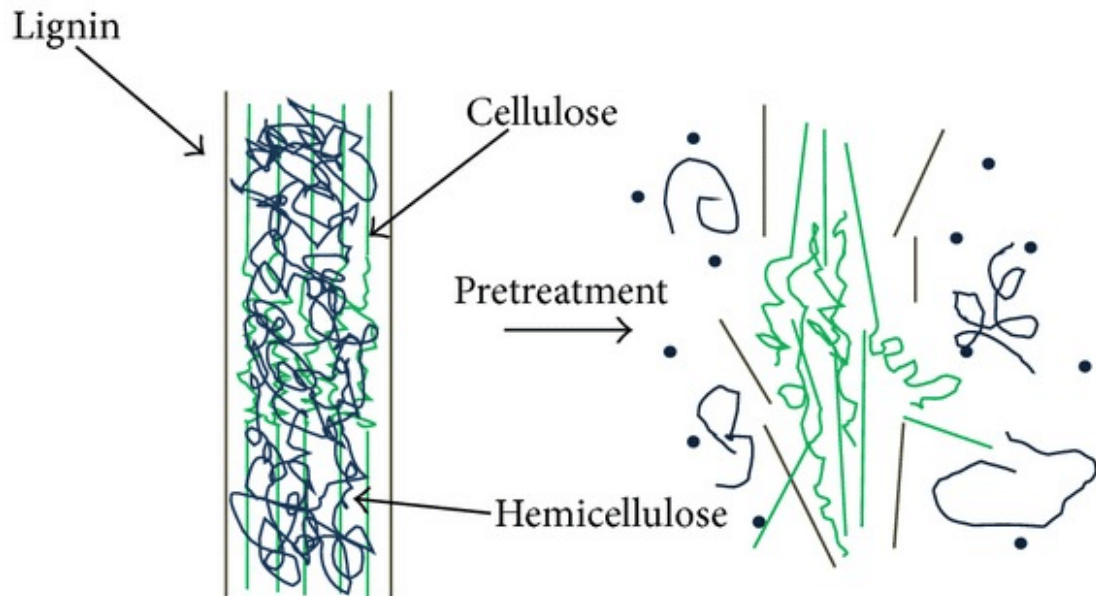


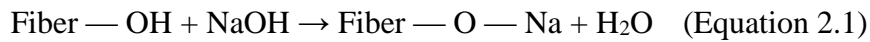
Figure 2.4: Schematic of the role of treatment of natural fiber. (Kumar et al., 2009)

#### 2.2.2.1 Alkaline Treatment

Alkaline treatment is generally carried out in ambient temperature and pressure. This treatment involves alkaline solutions, such as sodium hydroxide, calcium hydroxide or ammonia for the treatment of natural fiber, to remove lignin and part of hemicellulose and to efficiently increase the accessibility of cellulose (Badiei et al., 2011). The treatment on natural fibres by sodium hydroxide (NaOH) is one of the most used chemical treatment of natural fiber to modify the cellulosic molecular structure especially used to reinforce thermoset and thermoplastic (Li et al., 2007) (Kabir et al., 2012). The important modification done by this treatment is it changes the orientation of highly packed crystalline cellulose order and forming an amorphous region. This treatment also disrupting the hydrogen bonding in the network structure and thus increasing surface roughness (Li et al., 2007). This gives more access to penetrate chemicals. In the amorphous region, cellulose micro-molecules are separated at large distances and the spaces are filled by water molecules (Kabir et al., 2012). Addition of



aqueous sodium hydroxide (NaOH) to natural fiber ionize the hydroxyl group to the alkoxide as shown in Equation 2.1 (Kushwaha and Kumar, 2010):



As a result, hydrophilic hydroxyl groups are reduced and hence the fibres moisture resistance property is increased (Li et al., 2007). It also removes some portion of hemicelluloses, lignin, pectin, wax and oil covering materials from the natural fiber after alkaline treatment. Figure 2.5 present the schematic view of the before and after alkaline treatment of the cellulose fibre structure.

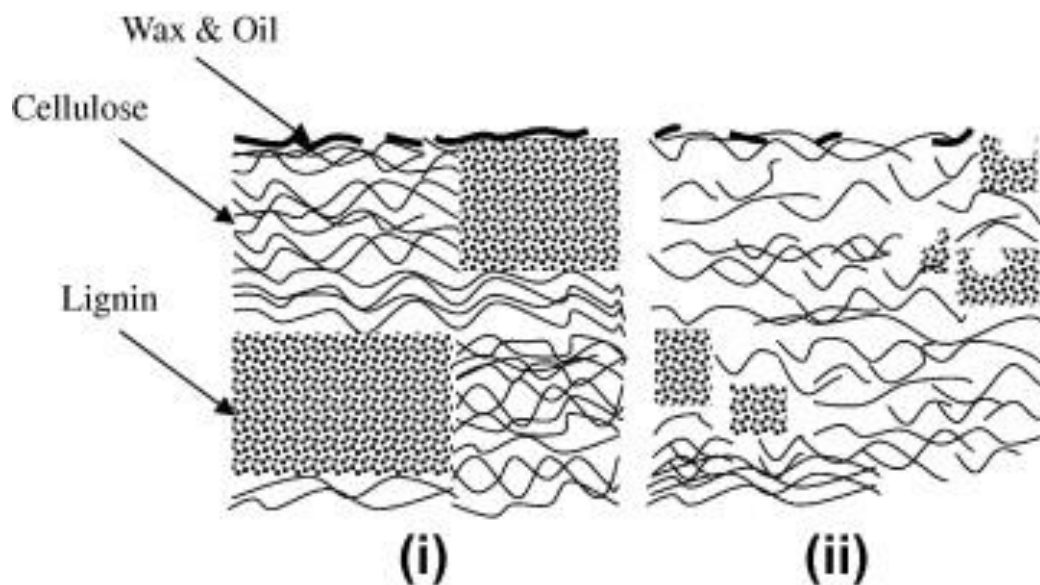


Figure 2.5: (i) Cellulose fiber structure before alkaline treatment

(ii) Cellulose fiber structure after alkaline treatment

(Chandrasekar et al., 2017)

#### 2.2.2.2 Silane Treatment

Silane is known as efficient coupling agents extensively used in polymer composites and adhesive formulations (Xie et al., 2010). It undergoes several stages of hydrolysis, condensation and bond formation during the process of treatment of the natural fiber. In the presence of moisture and hydrolysable alkoxy groups, during

hydrolysis, silanols are formed (Sreekala et al., 2000) which is shown in Figure 2.6. During condensation process, one end of the silanol reacts with the hydroxyl group of cellulose while the other end reacts with the functional group from the matrix (Sreekala et al., 2000) which is shown in Figure 2.7. This co-reactivity offers molecular continuity across the interface of the composites. Thus, the well fiber-matrix adhesion improves and stabilizes the properties of the composite (Kabir et al., 2012). There are micro-pores on the surface of natural fibers and silane agent acts as a surface coating which penetrates into the pores and mechanically interlocked coating on the surface of fibers (Kabir et al., 2012).

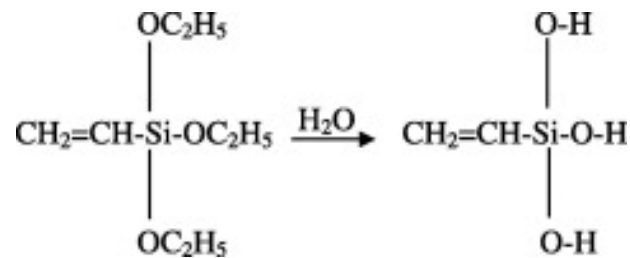


Figure 2.6: Structure of silanol after hydrolysis process

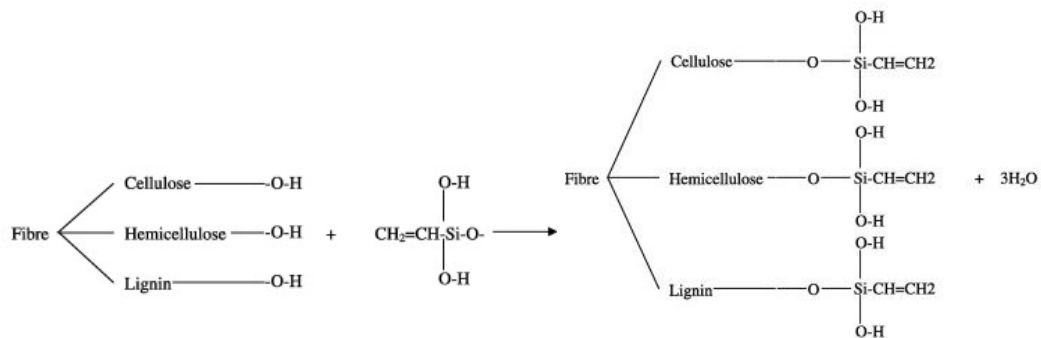


Figure 2.7: Silanol reacts with hydroxyl group of cellulose and functional group of matrix during condensation process.

### 2.2.2.3 Acid Hydrolysis

Acid hydrolysis can be performed with diluted or concentrated acids, normally sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) and hydrochloric acid (HCL), but these last are more hazardous, highly corrosive for reactors and equipment and therefore must be recovered after the

process (Galletti and Antonetti, 2012). Acid hydrolysis is less attractive due to the generation of high number of inhibitory products such as furfurals, 5-hydroxymethylfurfural, phenolic acids, and aldehydes (Kumar et al., 2009). The corrosive and toxic nature of most acids requires a suitable material for building the reactor which can sustain the required experimental conditions and corrosive nature of acids (Kumar et al., 2009).

#### **2.2.2.4 Organosolvation (Organosol) Treatment**

In the organosolvation process, an organic or aqueous organic solvent mixed with inorganic acid catalysts (HCl or H<sub>2</sub>SO<sub>4</sub>) is used to break the internal bonding of lignin and hemicellulose (Kumar et al., 2009). The lower molecular weight aliphatic alcohols are the most frequently used solvents in this treatment. Regarding the type of alcohol, it is noticed that normal primary alcohols are better agents than the secondary or tertiary alcohols for delignification, even though the mixtures of n-butyl-alcohol-water appeared to be the most efficient in removing lignin from wood (Zhao et al., 2009). Low boiling point alcohols, mainly methanol and ethanol, seem to be the most suitable organic liquids for use in this treatment because they are low cost and easy recovery (Zhao et al., 2009). Ethanol is safer because ethanol is less toxic than methanol, but it is always conducted under high pressure with increase of the equipment cost (Galletti and Antonetti, 2012). This treatment efficiently removes lignin from lignocellulosic materials but most of the hemicellulose sugars are also solubilized by this process (Mesa et al., 2011). Figure 2.8 shows the process flowchart of methanol and ethanol pretreatment.

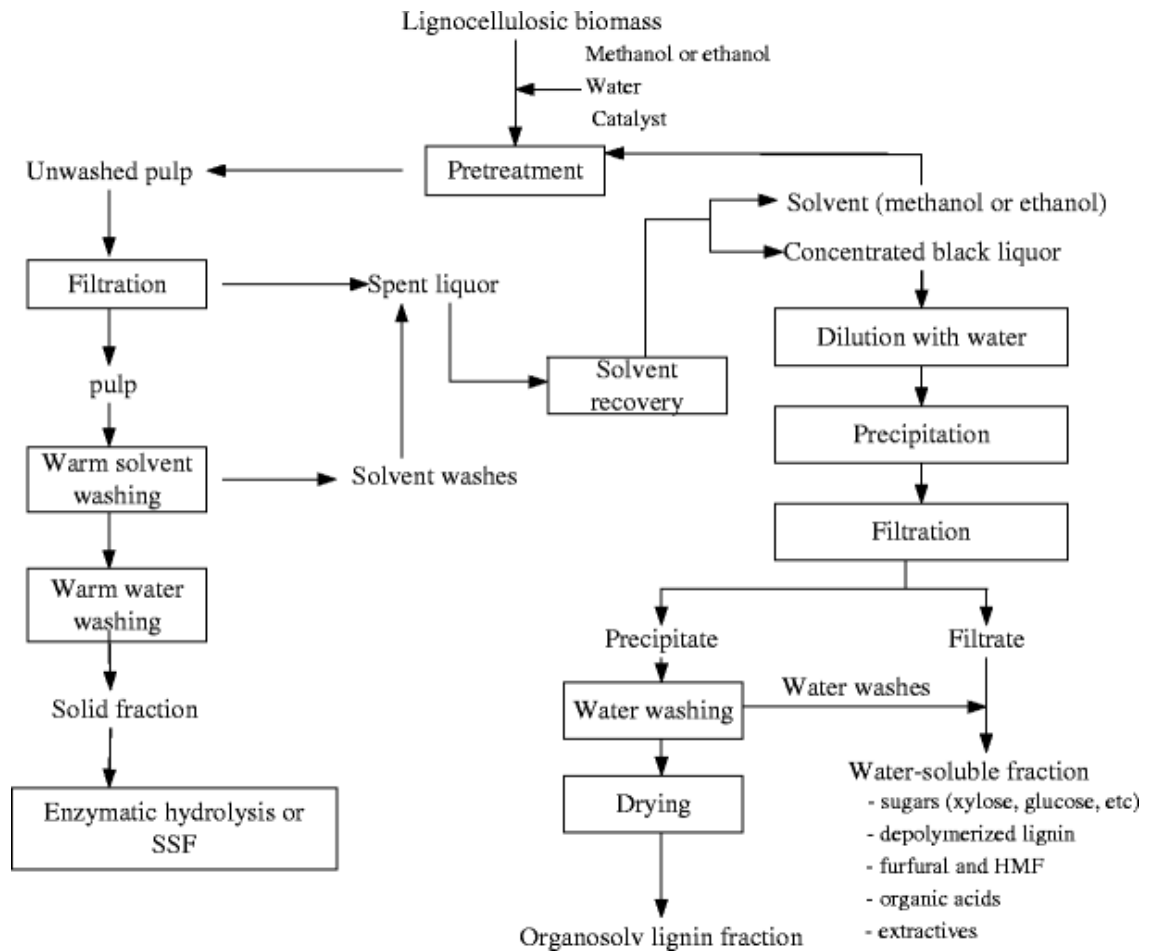


Figure 2.8: Flowchart of methanol and ethanol pretreatment process. (Zhao et al., 2009)

### 2.2.2.5 Ionic Liquid Treatment

Ionic liquids (ILs) are known as molten salts with low melting point (below 100 °C). Ionic liquids (ILs) are very talented biomass solvents that reduce recalcitrance, enabling network deconstruction of the lignocellulosic. Their high chemical and thermal stability and negligible vapor pressure are some of the advantages against other organic solvents (Zhu et al., 2016). ILs reduce cellulose crystallinity, while it increases cellulose accessibility and favouring high cellulose to glucose conversions (Xu et al., 2016). As a result of the immeasurable combinations of cations and anions that can form ILs, it often called designer solvents (da Costa Lopes et al., 2013). However, the cost of the ionic liquid as reagent as compared to other chemicals used in pretreatments (NaOH, H<sub>2</sub>SO<sub>4</sub>, ammonia), the difficulties to recover the IL, the high viscosity of most

of the ionic liquids and the low solid loadings used are factors that needed to be fulfilled before an industrial process is developed (Rigual et al., 2018). Furthermore, after the removal of lignin and other extractives, a potentially complex set of steps including precipitation by antisolvents such as deionized water or alcohols is required (Galletti and Antonetti, 2012).

#### **2.2.2.6 Ozonolysis**

Pretreatment of lignocellulosic materials can be treated using ozone, which can effectively degrade lignin and part of hemicellulose of the natural fiber. Ozone is powerful oxidizing agents ( $E_0 = 2.07 \text{ V}$ ,  $25 \text{ }^\circ\text{C}$ ), soluble in water (110 mg/L,  $25 \text{ }^\circ\text{C}$ ), and readily available for use after its production from oxygen in a steadily endothermic reaction (Travaini et al., 2016). In addition, ozone is strongly reactive toward compounds with conjugated double bonds and functional groups with high electron density (de Barros et al., 2013). Thus, lignin is the part most likely to be oxidized in this ozonolysis of lignocellulosic materials due to its high C=C bond. Biomass component is attacked by ozone by releasing soluble low molecular weight compounds, with a prevalence of organic acids such as formic and acetic acids, which can result in a drastic drop of pH (de Barros et al., 2013). However, this process is beneficial because the degradation products do not interfere with the subsequent enzymatic hydrolysis and fermentation steps. Also, the low energy consumption of ozonolysis is attractive because it takes place at room temperature (Kumar et al., 2009).

#### **2.2.3 Review of previous work on chemical treatment used and properties measured**

Nadlene et al. (2018) used roselle and the roselle was treated with NaOH and silane agent. They studied the properties of water absorption, thermal, impact and tensile. Most of the properties was improved while there is reduction in impact

properties after the roselle is treated. Jute was treated with NaOH and sodium chlorite, NaClO<sub>2</sub>, to investigate the effect on water absorption properties and tensile properties (Orasugh et al., 2018). As a result, both properties had improved after the treatment (Orasugh et al., 2018). Shaheen and Emam (2018) had characterized the treated wood sawdust by NaOH and NaClO<sub>2</sub>. NaOH treated wood sawdust was tested under tensile test and flexural test where both properties have been improved (Sullins et al., 2017). The treatment of ozonolysis and NaOH had been used for sugarcane bagasse to study the thermal properties using thermogravimetry analysis (TGA and DTG) which giving a positive effect on the thermal stability (Perrone et al., 2016).

Furthermore, flexural properties had been determined from the NaOH treated kenaf and it was showing a positive effect on flexural strength while giving a negative effect on flexural modulus (Fiore et al., 2015). Three mechanical properties such as tensile properties, compression properties and flexural properties were improved by NaOH treated bamboo while 6% NaOH has the highest flexural modulus (Manalo et al., 2015). According to Zhu et al. (2015), NaOH treated flax and silane treated flax enhanced the flexural strength and modulus while acetylation has no much effect on the flexural properties. Kabir et al. (2013) reported that NaOH treated hemp has lower tensile properties than silane treated hemp. Alsaeed et al. (2013) said that NaOH treated palm has higher tensile properties with lower concentration of NaOH. Last but not least, according to Faruk et al. (2012), the NaOH treated kenaf had improved the flexural strength by 36%. Table 2.1 below shows the summary of previous work on chemical treated NFRCs.

Table 2.1: Previous work on alkaline treated NFRCs

Fiber	Chemical Treatment	Results	Reference
Roselle	NaOH + Silane	Reduced the amount of water absorption from 2.2% to 1.7% for 6% NaOH, 2% for 3% and 9% NaOH and 1.4% for the addition of silane  Lower impact property  Silane improved TS by 41%	(Nadlene et al., 2018)
Jute	NaOH + NaClO <sub>2</sub>	Lower amount of water absorption from 11.31% to 8.75%.  TS was improved by 35% to 50%	(Orasugh et al., 2018)
Wood Sawdust	NaOH + NaClO <sub>2</sub>	-	(Shaheen and Emam, 2018)
Hemp	NaOH	The addition of MAPP improved the TS and FS by 37%.	(Sullins et al., 2017)
Sugarcane bagasse	Ozonolysis + NaOH	Treated fiber shows higher degradation temperature.	(Perrone et al., 2016)
Kenaf	NaOH	Enhanced the tensile modulus by 73%.	(Fiore et al., 2015)
Bamboo	NaOH	6% NaOH had the highest TS which is 10% higher than untreated composite and for 4% NaOH had a 2.6% increment of TS. However, there was 15% reduction in TS for 8% NaOH.	(Manalo et al., 2015)

Table 2.1: Previous work on alkaline treated NFRCs

Flax	NaOH	NaOH treatment increased TS by 24.1% while the addition of silane agent further improved the TS by 38.6%.	(Zhu et al., 2015)
	Acetylation		
	Silane		
Hemp	NaOH	4% NaOH shown the lowest tensile properties	(Kabir et al., 2013)
	Silane	TS improved by 44.7%.	
Palm	NaOH	9% NaOH exhibited the lowest TS (110MPa) while 3% shown highest TS (400MPa).	(Alsaeed et al., 2013)
Kenaf	NaOH	Flexural strength being improved by 36%	(Faruk et al., 2012)

### 2.3 Wood Sawdust

Wood is an abundant raw material over the world. It has a complex chemical structure that consists mainly of cellulose, hemicellulose and lignin. The composition is mainly depending on the biomass type. For wood, the composition is around 35–45 % cellulose, 25–35 % hemicellulose and 20–30 % lignin (Arkkola, 2015) as shown in Figure 2.9. Figure 2.10 shows the structural constituent of natural fiber cell.

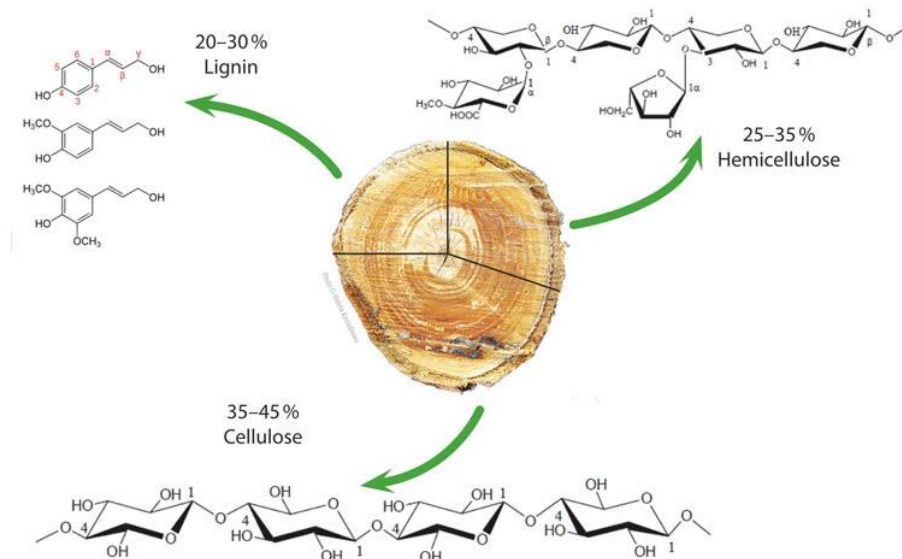


Figure 2.9: Composition of wood (Arkkola, 2015).



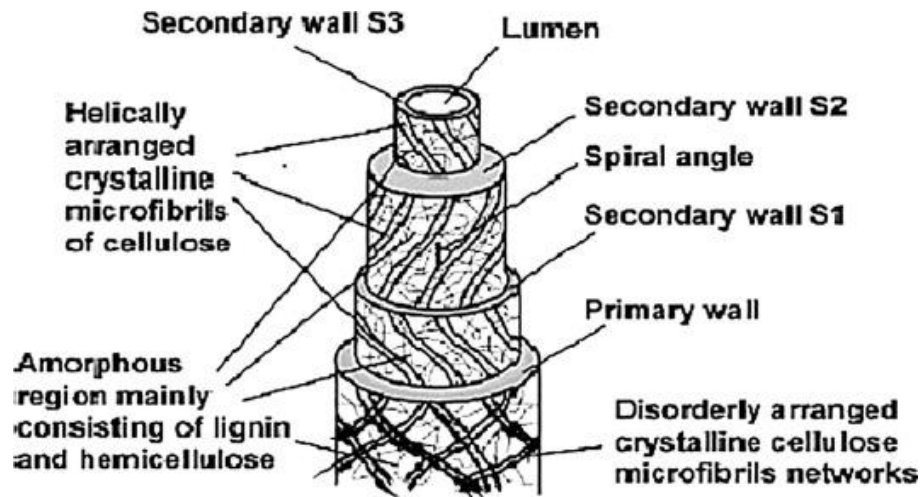


Figure 2.10: Structural constituent of natural fiber cell (Rong et al., 2001).

There is different bonding between cellulose, hemicellulose, and lignin. They are mainly coupled by a hydrogen bond. However, there is other chemical bonding between hemicellulose and lignin, as a results lignin is isolated from natural lignocelluloses, always contains a small amount of carbohydrates (Chen, 2014). The chemical bonds between the hemicellulose and lignin mainly refer to the chemical bonds on the side chains of hemicellulose molecules and lignin, and carbohydrates, among the galactose residues, arabinose residues (Chen, 2014). Thus, research on the separated lignin-carbohydrate complexes (LCCs) is gained with this knowledge.

### 2.3.1 Cellulose

Cellulose is the main component in natural fiber. Although the structure and composition for every type of wood vary widely, the cellulose content usually comprises for 35–50 % of dry weight. Through the study of the supramolecular structure of natural cellulose illustrated that the crystalline and non-crystalline phases intertwined to form cellulose (Chen, 2014) as shown in Figure 2.11. The non-crystalline phase is assumed as amorphous state due to most of hydroxyl groups on glucose are amorphous. However, hydrogen bonds are formed due to the huge amounts of hydroxyl groups in the crystalline phase, and these hydrogen bonds build up a huge network that

directly contributes the compact crystal structure (Zhang et al., 2008). In most of the conditions, the cellulose is surrounded by hemicellulose (dry matter accounting for 20–35 %) and lignin (dry matter accounting for 5–30 %).

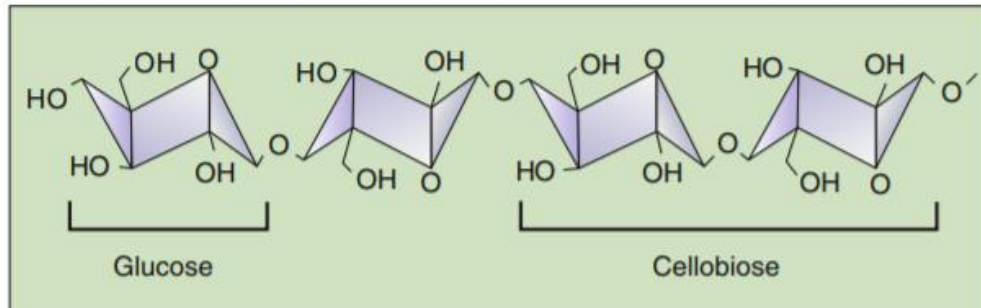


Figure 2.11: Molecular chain structure of cellulose (Chen, 2014).

### 2.3.2 Hemicellulose

Unlike cellulose, hemicellulose is a copolymer consist of heteropolysaccharides. The structure and composition of hemicelluloses for softwood and hardwood are different. Hemicelluloses play a critical role in the bonding capacity of fibers, i.e. the ability to form interfiber bonds, which gives the strength to the paper fiber network. Hemicellulose has a random, amorphous structure with little strength which is different to cellulose that is crystalline, strong, and resistant to hydrolysis. It easily hydrolysed by dilute acid or base, but nature gives an arsenal of hemicellulose enzymes for its hydrolysis (Li, 2011).

### 2.3.3 Lignin

Lignin is one of the most abundant organic polymers in natural fiber, just behind cellulose. It is the chemical composition of gymnosperm and angiosperm. The content of lignin in wood is 20–40% depending on the different wood species (Li, 2011). Moreover, lignin is mainly concentrated in the region of the middle lamella. Lignin is bound together with the cellulose and hemicelluloses. The position of lignin within lignocellulosic matrix is shown in the Figure 2.12.

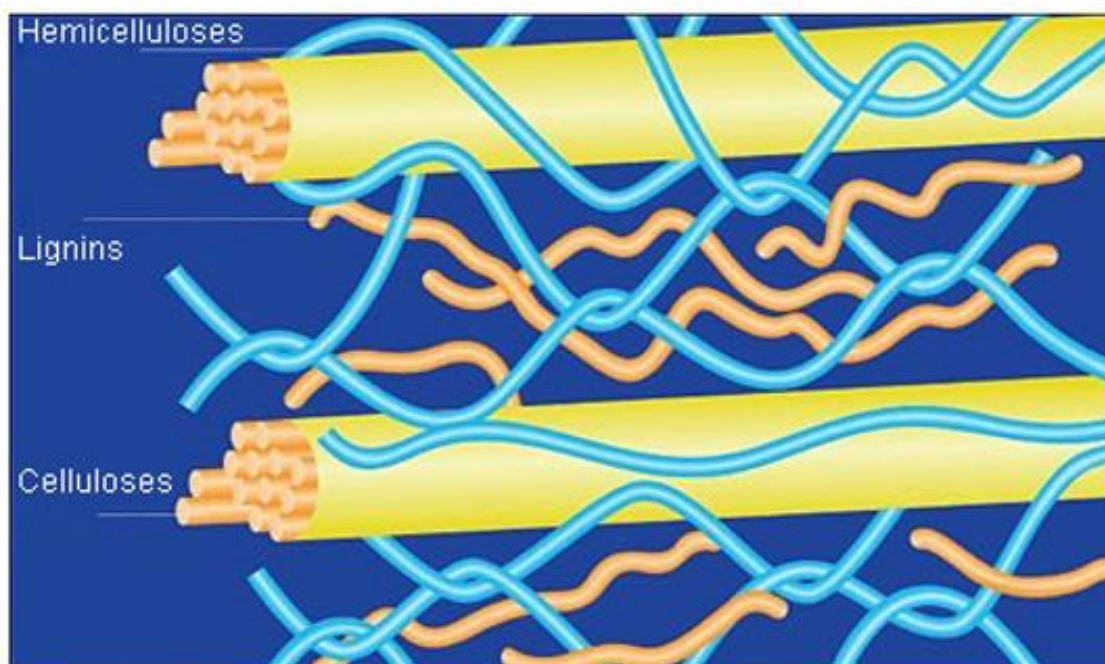


Figure 2.12: The position of lignin within lignocellulosic matrix

## 2.4 Thermoplastic

Thermoplastic polymers change their properties when heated and cooled. Thermoplastics become soft when heat is applied and on the other hand have a smooth, hard finish when cooled. Thermoplastic polymer has high molecular weight due to it is made up of long, unlinked polymer molecules. They rely on other interactions, such as dipole-dipole interactions, aromatic ring stacking, or Van der Waals forces because the molecular chains are unlinked (Kristoff, 2018). Thermoplastics generally form a crystalline structure below a certain temperature, resulting in a smooth surface finish and significant structural strength. Above the critical temperature, thermoplastics are elastic. Thermoplastic is a recyclable polymer because thermoplastics can be melted and reused without any change in material properties. The wastes are normally ground into chips, melted, refined to remove impurities, and reused as reclaimed material (Kristoff, 2018). The most commonly found thermoplastic polymers are polyethylene (PE), polypropylene (PP), Polyvinylchloride (PVC), Polystyrene (PS),

polytetrafluoroethylene (PTFE) or normally known as Teflon and polyamide which is known as nylon. Table 2.2 shows the recycling symbol and the properties of thermoplastic polymers.






PE is normally classified as low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is used mainly in film applications due to its toughness, flexibility and relative transparency, making it popular for the applications where heat sealing is necessary. HDPE is the most widely used plastic for many types of bottles and containers. Unpigmented bottles are translucent, having good barrier properties and high stiffness, therefore it is well suited to packaging products with a short shelf life such as milk. Furthermore, HDPE is good in chemical resistance, therefore it also used for packaging many household and industrial chemicals such as detergents and bleach.

PP having a good chemical resistance and high melting point, about 160°C making it good for hot-fill liquids. PP also has an excellent optical clarity in biaxially oriented films and stretch blow molded containers. The low moisture vapour transmission and inertness toward acids, alkalines and most of the solvent making PP is suitable to be used in food packaging application.

PS is a versatile plastic which can be rigid or foamed. General properties of PS are clear, hard and brittle. However, it has a relatively low melting point. PS is often combined with rubber to prepare high impact polystyrene (HIPS) which is used for packaging and durable applications where toughness is critical, but not clarity.

PVC has high impact strength, brilliant clarity and excellent processing performance. In addition, PVC has good grease, oil and chemical resistance, weatherability, flow characteristics and stable electrical properties. The vinyl products can be broadly divided into rigid and flexible materials.

Table 2.2: Recycling symbol and the properties of thermoplastic polymers (Attaran et al., 2017)

Thermoplastic Polymer	Recycling Symbol	Properties
HDPE		Stiff, strong, tough, resistance to chemical and moisture and easy process
PVC		Stiff, medium strong and transparent material, resistance to chemical, grease and oil, good flow characteristics and stable electrical properties
LDPE		Flexible, strong, tough, easy to seal, resistance to moisture
PP		Harder, denser, transparent and resistance to heat and chemicals
PS		Clear, hard and brittle material; foaming produces an opaque, rigid, lightweight material with impact protection and thermal insulation properties

## 2.5 Natural Fiber Reinforced Thermoplastic Composite

The demand for natural fibre composites is increasing due to the growing environmental awareness has resulted in a renewed interest in the use of natural for various application such as automotive component, packaging and the aerospace industry. The recent study is considering in the field of natural fibers as a reinforcement

in thermoplastic matrix. This is because of natural fiber serve as an inexpensive, biodegradable and nontoxic alternative to glass or carbon fiber (Malkapuram et al., 2009).

In pace with cost saving aspects and the ecological benefits, the main motivation driving natural fiber reinforced plastic composite developments are related to the mechanical property profiles of natural fibers, which indicate a substantial reinforcement potential (Sobczak et al., 2012). Thermoplastic composites reinforced with natural fibers are having good mechanical and recycling properties. The low density of natural fibers may results in lighter weight structure as compared to other synthetic fibers. However, their mechanical performance is not as good as the synthetic fiber reinforced thermoplastic composite and due to the hydrophilic characteristic of natural fiber results that a suitable treatment is required before further processing. Table 2.3 shows the summary of previous work on the natural fiber reinforced thermoplastic composite.

Table 2.3: Summary of previous work on the natural fiber reinforced thermoplastic composite

Parameter	Method	Results	Reference
10, 20 and 30 phr of Aluminium Phosphate (APP) into 20 wt% kenaf (KF)/PP and 20 wt% Rice husk (RH)/PP	Counter-rotating twin screw extruder + Compression molding	Flexural modulus (FM) of KF/PP is slightly higher than RH/PP due to higher content of cellulose. At 10phr APP, it has the highest FM, but the trend decreased at 20phr APP. At 30phr APP, RH/PP shows a slight increase in FM.	(Arjmandi et al., 2017)