PRODUCTION, CHARACTERIZATION AND MECHANICAL EVALUATION OF BIOCOMPOSITE BASED ON BANANA PSEUDOSTEM FIBRE AND AGAR

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by

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ABSTRAK

Kajian ini dijalankan untuk membangunkan cara penghasilan biokomposit berasaskan gentian batang pisang dan agar-agar. Pelbagai nisbah gentian dan agar-agar digunakan untuk menghasilkan sebatian komposit (100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90 dan 0:100) dengan menggunakan pengadunan kering. Bod biokomposit telah dihasilkan menggunakan kaedah penekan panas. Kesan nisbah gentian kepada agar-agar terhadap ciri-ciri bod biokomposit telah dikaji. Bod biokomposit juga telah dicirikan dengan analisis spektroskopi inframerah transformasi Fourier (FTIR), analisis termogravimetrik (TGA), mikroskopi electron penskanan (SEM). FTIR telah dijalankan untuk mengkaji perbezaan kumpulan berfungsi yang terdapat dalam biokomposit bod yang dihasilkan dengan bahan asas. Analisis terma dilakukan untuk melihat kadar degradasi. Dari kajian FTIR dan TGA mennjukkan tiada sebarang perubahan yang ketara pada biokomposit bod. Analisis SEM digunakan untuk memerhati kehadiran liang-liang yang terdapat dalam gentian bod batang pisang, agar bod dan ruang diantara gentian. Serapan air meningkat dengan kehadiran agar manakala pembengkakan pengembangan menunjukkan tren yang berbeza. Ciri-ciri mekanikal bod menunjukkan perbezaan tren mengikut jumlah agar. Kekuatan tegangan meningkat apabila nisbah agar meningkat sehingga 50 nisbah, kemudian ia menunjukkan penurunan. Tetapi modulus tegangan, ia menunjukkan penurunan pada 80 nisbah agar. Kekuatan ikatan dalaman, menunjukkan trend yang sama seperti kekuatan tegangan, manakala ciri kelenturan menurun pada 70 nisbah agar. Kekuatan hentakan

bagaimanapun tidak menunjukkan sebarang kebergantungan yang jelas nisbah agar terhadap dalam bod biokomposit.

PRODUCTION, CHARACTERIZATION AND MECHANICAL EVALUATION OF BIOCOMPOSITE BASED ON BANANA PSEUDOSTEM FIBRE AND AGAR

ABSTRACT

The study was conducted to develop a method of making biocomposite boards based on banana pseudostem fibre and agar. Banana pseudostem fibre and agar were both grounded to powder form. Fibre and agar mixtures of various ratios (100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90 and 0:100) were prepared by dry-blending. Biocomposite boards were produced by using the hot press method. The effect of the ratio of fibre to agar on the properties of the biocomposite boards was studied. The biocomposite boards were also characterised using Fourier Transform Infrared (FTIR) analysis, Thermogravimetric analysis (TGA) and Scanning Electron Microscopy (SEM). The FTIR was done to examine any changes in the functional groups of the biocomposite boards produced. The thermal properties were analysed by TGA to observe their degradation temperature. From the FTIR dan TGA results, no signifcant changes observed in biocomposite board. The SEM analysis showed that voids were observed in the banana pseudostem fibres, the agar phase, and the spaces between the fibres. The water absorption increased with agar content but thickness swelling was otherwise. The mechanical properties of the boards showed a different trend as far as agar ratio was concerned. The tensile strength increased with agar ratio up to 50 and then dropped off. The tensile modulus, however, dropped off when the agar ratio was at 80. The internal bond strength showed similar as tensile strength, and both flexural modulus and strength dropped off at 70 agar ratio. The impact strength, however, did not show a clear dependence on the agar ratio in the biocomposites board.

CHAPTER 1

INTRODUCTION

1.1 General

Synthetic fibres, such as glass fibre, have been used in composite materials since 80 years ago (Fowler *et* al., 2006). However, due to the environmental and health issues, many composites manufacturers are now changing to natural fibres to produce biocomposites. Even though biocomposites are made from natural fibres, some biocomposites are not green because of the resin used as the matrix is not biodegradable. The fully green biocomposites are composites that are made from natural fibres and biodegradable resin (Sealy, 2006).

The conventional composites were made by using various types of polymers and reinforcement materials to improve mechanical properties. Natural fibres were found to enhance and improve the properties of composites (Nyström, 2007). Utilisation of natural fibres in composites not only helped to protect the environment but also did not create health issues to human (Mantia & Morreale, 2011). Synthetic fibres production has been a strong contributor to carbon emission and waste. Synthetic fibres also might cause serious bronchopulmonary disease due to the inhalation during exposure to synthetic fibres (Pimentel et al., 1975).

One of the advantages of using natural fibres in composites was the lower cost than synthetic fibres. Natural fibres are usually fully biodegradable after disposal and not harmful to the environment. Natural fibres are resistant to electric and light, can be recycled, and abundant (Pickering *et* al., 2016).

However, as the usage of natural fibres in the production of biocomposites keep increasing every year, it creates an unbalance in the environment, resulted in continued deforestation. To overcome this environmental issue, technologists are looking for alternative source of cellulosic materials to reduce the damage to forest while maintaining sustainability. The most suitable alternative source of cellulosic fibres is the agricultural waste such as hemp, rice stalk, wheat straw, *etc*.

In this study, fibres from banana pseudostem were used in making the green biocomposite board based on agar. Banana pseudostem fibres natural fibres that come from stems which are abundant in Malaysia. In Malaysia, banana is the second most consumed fruit, next to durian (Unit Perangkaan, Bahagian Perancangan, 2015) The banana plant is categorised as a large herb, full of fibre from root to top. As the demand for banana increases every year, the areas of banana plantation would also increase. Usually, after harvesting the banana pseudostem would be cut down and left to rot on the ground, releasing methane gas which is one of the greenhouse gases. Sometimes banana leaves are utilised as traditional packaging material, and the stems are used as farm feedstock or as fertiliser.

Banana pseudostem fibres have been used as the alternative lignocellulosic material in production of fibre based product such as pulp and papermaking (Hussain & Tarar, 2014), and as reinforcement materials in composites (Sapuan *et* al., 2006; Liu *et* al., 2009; Manickam Ramesh *et* al., 2016). Banana pseudostem fibres have high lignocellulosic content (K. Li et al., 2010) and also has the capability to be produced in a short period and as compared to other lignocellulosic material such as oil palm. Banana pseudostem fibres possess good physical and mechanical strength, with low production cost (Jústiz-Smith *et* al., 2008). Therefore, banana pseudostem waste can fully utilise as a lignocellulosic material in the production of biocomposite thus giving additional income to the farmers.

The conventional composite board was made by using various types of polymer resins give strength in their mechanical properties. The researchers found that using fibres as the reinforcing material in composite production could enhance and improve the properties of composites (Nyström, 2007). Due to the environmental concern, the usage of green material in the production of composite material would be the solution. Natural fibres with natural resins can be used as raw materials in the production of composites that can be used safely by human being (Mantia & Morreale, 2011).

It is well known that biocomposite board required a binder to help strengthen the composite. The most popular binder in the composite board is polymer resins. They have been widely used for years before the environment concern started to spread worldwide. The usage of conventional resin in composite board application has some serious environmental issue. In the fibreboard manufacturing, usage of urea formaldehyde as adhesive to formaldehyde emission.

As far as particle board production was concerned, the usage of formaldehyde based resin would cause formaldehyde emission which was harmful toward the environment and human health (National Toxicology Program, 2014). In addition, the usage of epoxy resin in composites required curing agents that can cause some serious health issue (Bourne *et* al., 1959).

In this study, agar was used as the binder for the biocomposite board. The agar will act as a binder in the biocomposite while improving the interaction between fibres and matrix. The suitability of agar resin was tested, and its effect on the properties of the biocomposite boards was elaborated in this study.

1.2 Problem Statement

Due to the problem that encountered with the conventional composite such as environmental problem and health issue, banana pseudostem fibre and agar were suggested as an alternative material in composite production. By this progression, it may also help to decrease the agricultural waste from banana pseudostem waste, which is usually left to rot on the soil. By utilising the banana pseudostem waste, it is not only can save the environment by decreasing the greenhouse effect, but also can give an extra income to the farmer.

1.3 Objectives

The objectives of this study are:

1) To establish method of producing biocomposite boards based on thermal and morphological properties

2) To characterize the biocomposite boards based on banana pseudostem fibre and agar

3) To study the effect of agar and fibre on the properties of the mechanical biocomposite boards based on banana pseudostem fibre and agar

CHAPTER 2

LITERATURE REVIEW

2.1 Composite

2.1.1 Introduction

Composite is made up from two or more components that contain different properties whether chemical or mechanical, that combine to form a new material with different properties from the individual component. Composite has already been used since the ancient time. Ancient Egyptian used mud and straw to produce adobe brick, and the resultant composite was stronger than the mud or the straw itself. Wood is an example of the natural composite, containing cellulose fibres that provide reinforcement and lignin that acts like glue. The combination of the matrices and reinforcement can improve strength, stiffness, and elasticity of a composite (Verma et al., 2012).

In industry, the usage of composites depends on their properties and functions. Composite technology has been expanding year after year with new research and improvement. A lot of research were done on composites to provide a better understanding that could be lead to new innovation. Many researchers are looking at the alternative new materials to produce an environmental friendly composites or biocomposites.

Tabletop, packaging, and building material are the examples of the usage and applications of the composite in our daily life. The application of composite continues to increase due to the need for improved performance. Automotive, sport, aerospace, military, marine, building and construction are major industries that use composite in their products and parts. Composites also can be made environmentally friendly when all the components are derived from the renewable sources (Mantia & Morreale, 2011).

2.2 Classification of composites

There are many types of composites which are classified into several categories. There are three categories of the basic engineering composite based on their matrices (Lukkassen & Meidell, 2007; AZoM, 2013); polymer composite, metal composite and ceramic composite. Polymer Matrix Composites are composed of a matrix from thermoset or thermoplastic. Metal Matrix Composites are composed of the metallic matrix such as aluminium and a dispersed ceramic (oxides, carbides) or metallic phase. Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibres of other ceramic material.

Classification of composites is also done based on the structure of reinforced material. There are particulate composite, fibrous composite and lamination composite. The particulate and fibrous composite consist of reinforcement of particle or fibrous that dispersed in matrices. The difference between particles and fibrous is in term of size and shape of reinforcement. The laminate composite consists of a layering of fibre with different fibre orientation (Khandan, et al., 2012). The fibrous composite can be subdivided by natural fibre or synthetic fibre composite. Meanwhile, in wood panel composite, it contains several types of product based on their density, particle size and process (Suchsland & Woodson, 1987).

2.3 Biocomposites

Usage of synthetic materials, either resin or fibre gains many interests because of their properties that are very compatible and also due to high demand in industries such as aerospace, thermal insulation, automotive and so on. The use of synthetic material in composites has been started about 80 years ago. Due to many issues caused by the synthetic materials, such as environmental issue, health, sustainability, and also cost of production the demand for the alternative materials to substitute this synthetic materials has been increasing.

The source of alternative material that starts to gain attention is the usage of biomaterials, derived from natural resources. The alternative material would include the biomaterial from fibre or resin. A mixture of both biomaterials can be used to form a new composite material called as green composite, or biocomposite. Biocomposite or green composite is defined as composite materials produced from two or more materials that originated from nature.

Natural fibres derived from plant sources (lignocellulosic material), animal (silk, wool, and hair) and mineral sources (stone wool) are used as the reinforcement in biocomposites. While in terms of resin, matrices can be obtained from a natural polymer such as from animal (blood), and plant (vegetable oils, starch, and agar). There is also biomaterial that is derived from starch such as polylactic acid (PLA) that is popular as the matrix for the biodegradable composite.

Moreover, studies showed that biomaterial has excellent properties. Natural fibre is known for high strength, high stiffness (Mohammed et al., 2015), and high thermal insulation properties (Zach et al., 2013). Natural fibre is also light, low cost, and biodegradable (Sahari & Sapuan, 2011). The excellent properties of natural fibres mentioned above make them popular as fillers for fibre reinforced polymer composite. They are more user-friendly as compared to other synthetic fibre such as fibreglass which can cause harm to health (Kilburn et al., 1992). Many studies had been done on the utilisation of natural materials in biocomposites. The increased utilisation of natural materials in biocomposites is due to the growing awareness of protecting the environment since the realisation of synthetic materials as non-environmentally friendly materials.

The work done on the production of the environmental friendly biodegradable composite from kenaf fibre and polylactic acid (PLA) (Nishino et al., 2003) showed comparable results with those traditional composites. They suggested that kenaf fibre was a good example to be used as reinforcement material in biodegradable biocomposite.

Furthermore, the proper usage of natural fibres and their waste can be used to promote sustainability in industry. A production of fibre reinforced composites based on natural fibre from date palm fibre can promote sustainability and enhancing productivity in automotive industry and their performance are competitive to other polymer composites (Al-oqla & Sapuan, 2014). Other research stated that nano-cellulose was used as a binder to produce the rigid and robust flax fibre. Research suggested that both nano-fibrillated cellulose and bacterial cellulose could act as natural binders (Fortea-Verdejo et al., 2016) which can contribute to a sustainable material resources.

Production of the green composite from green polypropylene and waste paper showed a superior modulus and crystallisation behaviour. The study suggested that green composite could reduce the cost of production and sustainabe (Iyer et al., 2016).

Zivkovi et al., (2017) studied the effect of moisture content on the impact properties of hybrid flax/basalt fibre biocomposite. They suggested that hybrid biocomposite was more significant in terms of impact behaviour, as compared to single composite. Fu et al., (2017) and Muthuraj et al., (2015) studied different types of natural fibres, biopolymers, and currently available natural resources that related to flame retardant, flammability, flame retardant mechanism, and also thermal properties.

This study focuses on the production of biocomposite board by using banana pseudostem fibre and agar. Both materials are produced and extracted from nature. Banana pseudostem fibre is harvested from of agricultural waste. While, agar comes from seaweed, which could to act as a binder.

2.3.1 Elements in composites

In composite technology, matrix and reinforcement material are the principal components that could affect the properties of the composite. Matrices are the continuous phase that binds other components in the composite. Matrices can be divided into two types, thermoset and thermoplastic. In general, the thermoset is an irreversible binder, where the cross-linking process takes place. Meanwhile, the thermoplastic is reversible binder where it could be re-melted and reused again.

The reinforcement materials are the disperse phase that that to provide strength for composite and stronger than the matrix. Percentage of reinforcing material used would influence mechanical properties of fibre reinforced composite; due to fibre has higher strength than the matrix. Type, size, orientation and composition of reinforcement material would also affect the properties of the composite.

Each element in composites plays their role towards end product. Application of the composite was determined by selection of the main element. For example, if the end usage was for the thermal resistant, fibre such as carbon fibres can be used because they were strong, thermally stable, and insensitive to moisture. Matrix chosen could be a thermoset resin, such as epoxy resin due to its high thermostability and high heat resistance as compared to the thermoplastic resin, which usually has lower thermostability.

2.4 Reinforcement

In composite, the reinforcement material also acts as load-bearing material. When the fibre is combined with matrix resin in a composite system, it will provide high strength and stiffness to the resulting composite. Based on **Figure 2.1**, there are several types of reinforcement in the polymer matrix. Reinforcement can be in particulate or fibrous form. Size, shape, orientation, and distribution of reinforcement material in the composite would significantly affect the properties of the composite.

Many types of fibres could be used as reinforcement materials. Commonly, fibres could be classified into two categories, natural fibres and synthetic fibres (man-made fibres). Natural fibres could be naturally retrieved from its origin such as animal, plant and mineral. Usually man-made fibres were chemically or physically manufactured. The use of natural fibres as reinforcement material has been gaining attention in both research and industrial sectors due to their ability to compete with synthetic fibres. **Figure 2.1** showed the major classification of fibres.

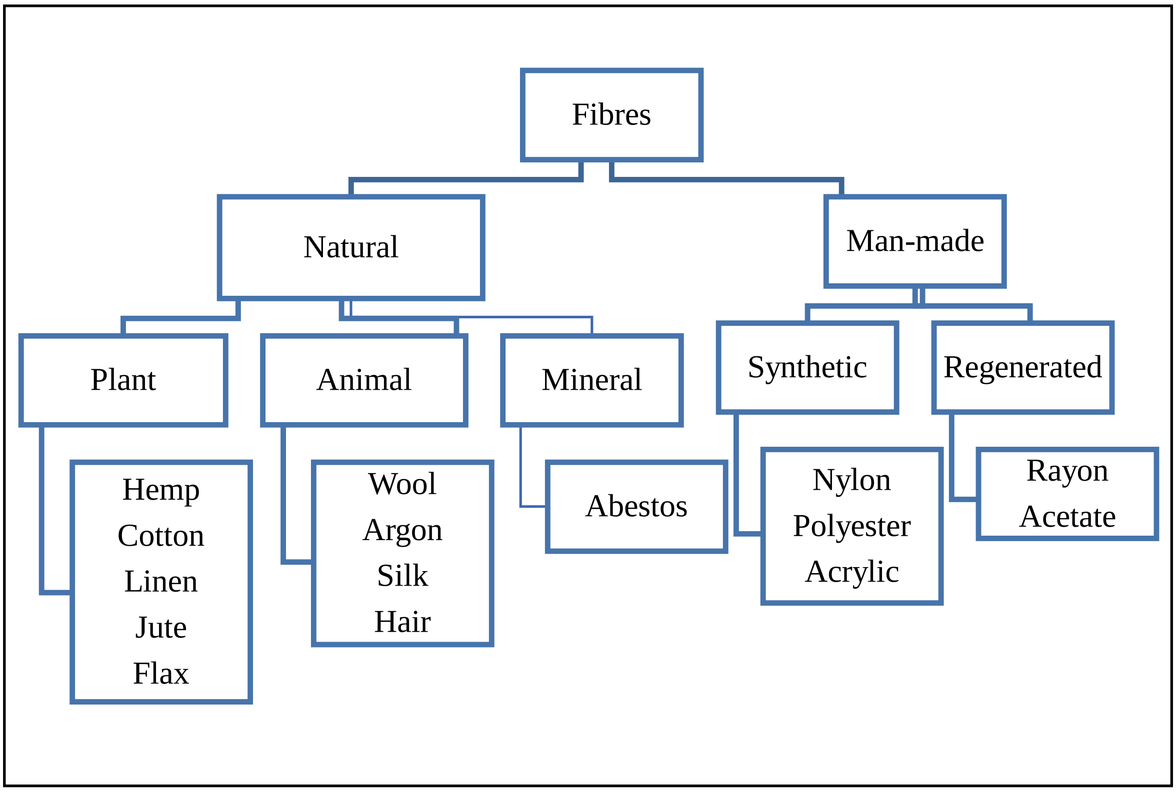

Figure 2.1: Classification of fibres (Jawaid & Abdul Khalil, 2011)

According to Herrera-Estrada (2007), automotive industry has been using natural fibre from plant based fibres as reinforcement in their structural application due to their high strength. In regards to the environmental issue, the current usage of plastic and oil-based products urged both industry and research sector to develop more biodegradable products (Song et al., 2009; Vieira et al., 2011).

2.4.1 Natural fibres

Nowadays, synthetic fibres have been replaced by natural fibres as reinforcement in various types of polymeric composites (Nirmal et al., 2015). Natural fibres usually produced from several resources and can be considered as environmentally friendly. Their properties were also comparable to synthetic fibres (Mohammed et al., 2015). Gupta & Srivastava, (2015) stated that plant fibre, animal fibre and mineral fibre are the major sources of natural fibre. The word 'natural' was referred to a substance that naturally exists and not man-made, while the word ‘fibre' was referred to as like hair, rope or thread-like structure which has high aspect ratio.

Figure 2.2 showed the sources of plant fibres based on their part, either from stem, bast, seed, grass, wood, and leaf. Each part of the fibre built up with different chemical composition. In plant fibre, natural fibre usually comes with cellulose composition. Cellulose is a natural polymer that provides high of strength and stiffness per weight (Hans & Bo, 2012). Generally, a natural fibre with higher mechanical properties possess higher cellulose content, a higher degree of polymerization of cellulose (Krässig & Kitchen, 1961), longer cell length, and lower microfibrillar angle (Hänninen et al., 2011).

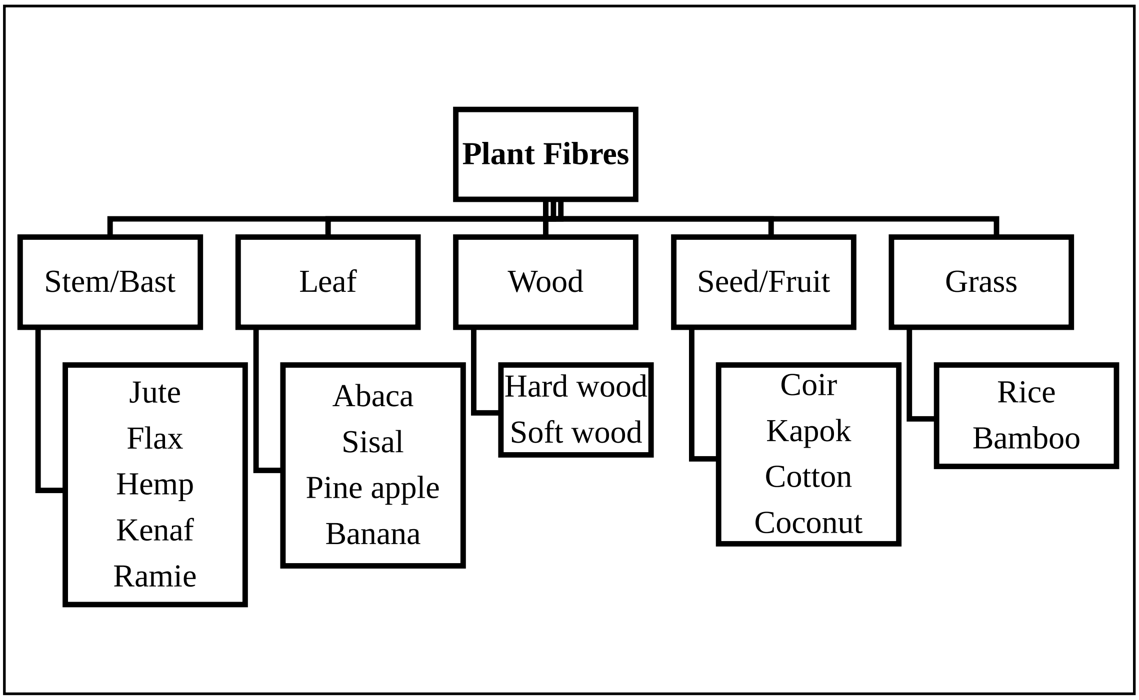

Figure 2.2: Different sources of plant-based natural fibres from different parts of the plants (Chandramohan & Marimuthu, 2011)

Another composition of natural plant fibre is lignin. Lignin is a complex hydrocarbon polymer with an aromatic constituent. It is totally amorphous and hydrophobic in nature. The other composition of natural fibre were pectin and waxes that supported the flexibility of natural fibres (John & Thomas, 2008).

Natural fibres are renewable, cheap, completely or partially recyclable and biodegradable. Produced with low cost, these materials gained interest to be used in the low-income countries. Many studies were done focusing on the usage of natural fibres as reinforcement in composite production.

The usage of natural fibres did not only help to manage waste disposal issue, but it also helped in reducing environmental problems. Natural fibres were also reported to be comparable with that synthetic fibres in term of low density, less machine wear, no health hazards, and a high degree of flexibility to the composite. (May-Pat et al., 2013). Furthermore, they can be used as a replacement to glass fibre as reinforcement in polymer composites (Ashik & Sharma, 2015).

A review study by Pickering et al. (2016) stated that natural fibres have been experiencing rapid development to be used as a reinforcement material in composite production as compared to the synthetic fibre, due to their low environmental harm, low cost, and their capability to be used in a wide range of applications.

In general, high performance is achieved by using natural fibres that contain high cellulose content. Natural fibres are different in term of their chemical composition and their structure. Depend on their species, growing condition, harvesting time, treatment, extraction method, and also storage method.

Natural fibres also have been used in the production of the composite in aerospace engineering (Balakrishnan et al., 2016), automotive and construction building materials (Y. K. Kim, 2012). Mallick (1993) focused on using natural fibre fabric as reinforcement of composite, the surface treatment of natural fibre, and the layout technique.

Huda et al., (2007); Masud Huda et al., (2007); Threepopnatkul et al., (2009) investigated the effect of silane treatments on the properties of natural composites based on newspaper fibre, kenaf fibre and pineapple leaf fibre, respectively. It was reported that silane treatments could improve mechanical properties by enhancing the adhesion properties and also very suitable in a moist environment as silane-modified fibres were moisture resistant (Bisanda & Ansell, 1991).

The potential of natural bagasse fibres was explored as reinforcement in polymer composite, and their mechanical properties were studied. They were comparable to other synthetic fibre such as glass fibre in terms of mechanical properties when used as reinforcement materials (Verma et al., 2012). Bagasse natural fibre also gained interest to be used in the production of binderless particleboard (different bagasse part) (Widyorini et al., 2005).

Furthermore, there was also the production of the binderless board, which included kenaf natural fibre (J. Xu et al., 2005). Production of all cellulose based fibreboard depended on the self-bonding properties that enhanced the hydrogen bond network, resulting in good mechanical performance (Arévalo & Peijs, 2016).

2.4.1(a) Chemical Components of Natural Fibres

The chemical composition of natural fibres varied with their types. Animal based natural fibres consisted mainly of protein while that for plant-based natural fibres consisted mainly of cellulose (Chandramohan & Marimuthu, 2011). For plant based natural fibres, they were called lignocellulosic fibre which is in the form of plant biomass. It mainly consisted of plant carbohydrates polymer (cellulose and hemicellulose) and also an aromatic polymer (lignin).

Lignocellulosic fibres usually came from various sources of biomass such as agricultural waste, industrial sector, and also forestry. Basically all plant fibre or lignocellulosic fibres were built mainly from sugar-based polymer (cellulose, hemicellulose) combined with lignin. These components also contributed to the formation of the cell wall. Cell wall could be formed from different layers based on their plant varieties (Alberts et al., 2002) which led to the different chemical composition.

Chemical composition also played an important role in determining the mechanical properties of fibre, which very useful in the production of composite based on lignocellulosic fibre (Komuraiah et al., 2014). The other properties that related to the chemical composition of fibre were their dimensional stability and their thermal degradation (Migneault et al., 2014; Razali et al., 2015).

Chemical compositions of plant fibre included cellulose, hemicellulose, lignin, extractive, ash, pectin and also wax. All these materials could be found in the cell wall of plant fibre cell. However, major chemical composition that always influenced physical and mechanical properties of fibres were cellulose, hemicellulose and lignin. **Table 2.1** showed the chemical major chemical composition of different natural fibres.

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Table 2.1: The chemical composition of some common natural fibre (Komuraiah et al., 2014; Ramamoorthy et al., 2015)

Fibre	Cellulose (Wt. %)	Hemicellulose (Wt. %)	Lignin (Wt. %)
Abaca	62.5	21	12
Bagasse	37	21	22
Banana	62.5	12.5	7.5
Bamboo	34.5	20.5	26
Coir	46	0.3	45
Cotton	89	4	0.75
Curaua	73.6	5	7.5
Flax	70.5	16.5	2.5
Hemp	81	20	4
Jute	67	16	9
Kapok	13.16	-	-
Kenaf	53.5	21	17
Oil Palm	65.0	-	29.0
Pineapple	80.5	17.5	8.3
Ramie	72	14	0.8
Rice Husk	35.0-45.0	20.0	19.0-25.0
Rice Straw	41.0–57.0	8.0-19.0	33.0
Sisal	60	11.5	8

2.4.1(b) Cellulose

Cellulose is one of the components that can be found in nature which come from a plant. It is an organic compound with formula $(C_6H_{10}O_5)_n$ which was discovered when Anselme Payen isolate it from the plant (Crawford, 1981). It is a major composition of the plant. It can be classified as a natural polymer. The main lignocellulosic material is aligned to form a natural composite with cellulose fibril along the length of fibre that embedded in lignin matrix (Jawaid & Abdul Khalil, 2011). Their composition or aligned are corresponding from their origin sources, whether from stem, leaf or fruit.

Cellulose is polysaccharides that contain glucose as a monomer. Glucose is linked by β (1→4) linked D-glucose to form a linear chain of cellulose polysaccharide. Wood, cotton, rope and all fibrous plant are made of fibrous cellulose. Cellulose is hydrophilic in nature, but it doesn't dissolve in water and melt at 457 ℃ (Krumm et al., 2016). The insolubility and the high melting point of cellulose are because of the structure and region that present in cellulose. The two regions are amorphous and crystalline regions. From the structure, there are plenty of hydroxyl group that attract water, but since they are in the polymer chain, making it difficult for water to dissolve cellulose.

Amorphous cellulose can be obtained by regeneration of cellulose with ethanol from their solution in the solvent system (Ciolacu et al., 2011). By treating cellulose with the strong acid, the amorphous structure of cellulose could be broken down to produce crystalline cellulose. The crystallinity of cellulose could be retained by esterification of iodine-catalyzed butyrate with crystalline cellulose to produce highly hydrophobic thermally stable cellulosic materials (Abraham et al., 2016). Vora & Shah (2015) produced microcrystalline cellulose from corn husk for pharmaceutical application.

Skinner (1932) stated that cellulose could be divided into four groups in industries. These include the use of cellulose in textile industries, paper making industries, purification of cellulose into cellulose derivatives and various uses of cellulose such as brush and mat fibres. **Figure 2.3** showed the molecular structure of cellulose. Cellulose is widely used in paper and board industries. In the history of synthetic polymer, rayon, cellulose nitrate, and cellulose acetate were derived from the cellulose.

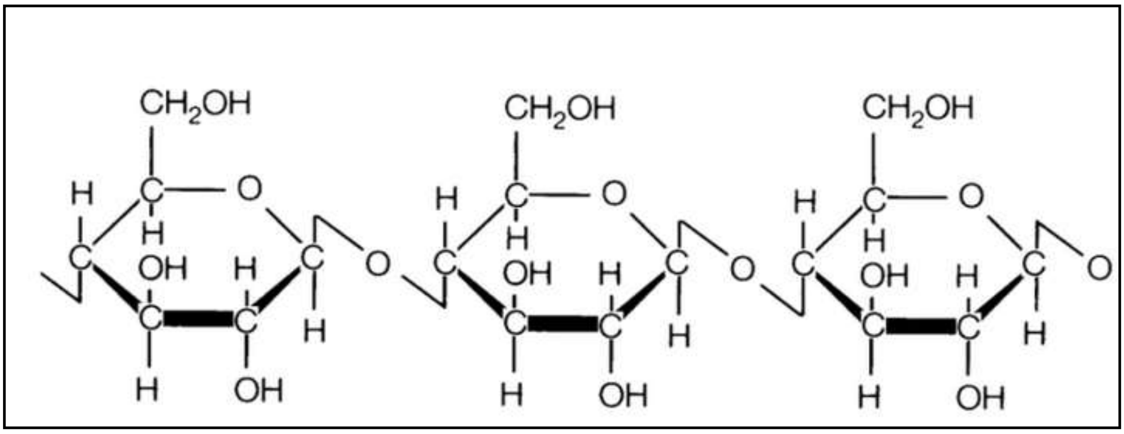

Figure 2.3: Molecular structure of cellulose. (Van, 2010)

The most important property in all cellulosic materials is their degree of polymerisation. High degree of polymerisation would lead to high mechanical properties of fibre hence helping in providing strength to plant (Levi & Sellen, 1967). The research done by Kim & Jang, (2013) showed that the degree of polymerisation of pristine cellulose would affect the mechanical properties, such as tensile strength and elongation at break of regenerated fibres.

2.4.1(c) Hemicellulose

The other major component in a plant or lignocellulosic material is hemicellulose. Like cellulose, hemicellulose functioning as a cell wall support material. Hemicellulose is a polysaccharide that link together from their monomer by beta-(1-->4)-linkage. As compared to cellulose that contains glucose as the only their monomer is only glucose, hemicelluloses are consist of mixed sugar such as xyloglucans, xylans, mannans and glucomannans (Whistler & Shah, 1978; Scheller & Ulvskov, 2010).

Structure and the content vary by different species and type of cell wall. Hemicellulose is short and branched polysaccharides with low molecular weight.

Unlike cellulose, hemicellulose is contained in the amorphous region. **Figure 2.4** showed the partial structure of hemicellulose (xylan).

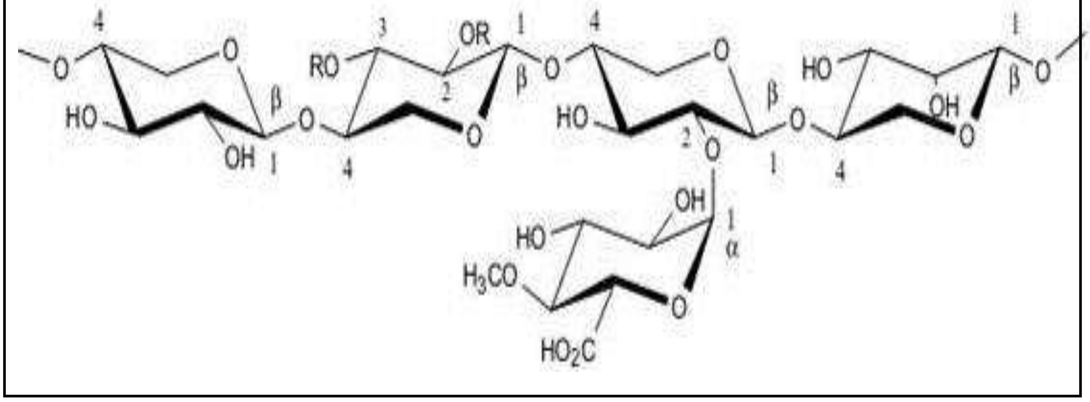

Figure 2.4: Partial structure of hemicelluloses (xylan) (Nhuchhen et al., 2014)

2.4.1(d) Lignin

Lignin is a complex material that can be found as an integral part of plant cell wall. All lignins are different in their chemical structure, mostly full with aromatic branched network structure, based on phenyl prophene basic unit. Three main components of lignin are coumaryl alcohol, coniferyl alcohol, and sinapyl alcohol which is known as monolignols (Frei, 2013). Lignin tightly bound together with other cell wall and act as natural glue for providing strength and stiffness to fibre and cell wall (Rubin, 2008). **Figure 2.5** shows the structure of three main components of lignin.

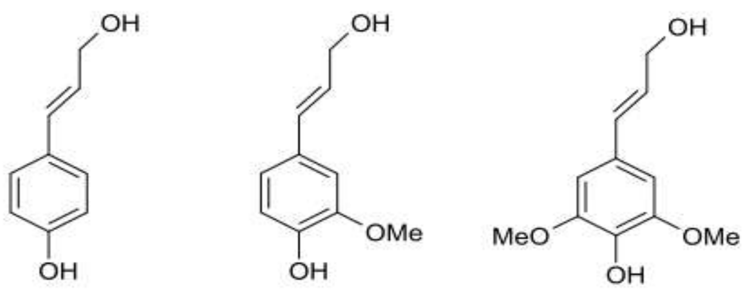

Figure 2.5: Structure of the softwood lignin precursor trans-coniferyl alcohol (Laine 2005)

2.4.2 Agricultural waste

Agricultural waste is natural (organic) and non-natural waste from farming industries that were produced from various farming activities. Due to the environmental awareness and sustainable practices, agricultural waste has been marked as a potential alternative material for wood and plastic based materials.

Agricultural waste fibres are mostly found in the developing country. In Malaysia, there are more than 70 million tonnes of agricultural waste produced annually. Every year, there are tonnes bundle of waste produced from the agricultural industry, causing major disposal problems. Various management practices for agricultural waste can lead to the emission of nitrous oxide which is one of the greenhouses gases.

To counter this problem, the waste can be utilised to the maximum and used for the production of the composite. Use of agricultural waste can contribute to large benefit as it is an emerging ‘green' economy base in energy efficiency. Carbon emission can be reduced and use of this renewable feedstock can be used to minimise waste by producing recyclable material.

Since too much of waste residue generated every year, the agricultural waste could be used as a substitute for wood and solving the worldwide shortage of wood especially in paper and fibre composite industries (Rosnah, 2011).

There are many studies about agricultural waste to produce composites. Corn husk (Norashikin & Ibrahim, 2009), and seaweed waste (Jaya Chitra & Vasantha Kumari, 2012) were used in the production of biodegradable composite. Fire retardant and sound absorbing material could be produced from sago waste (Zainab et al., 2013). Heat insulation can be produced by using sugarcane bagasse and coconut fibre (Ramlakhan, 2006; Chuen et al., 2015).

Palm oil waste, coconut husk, and bagasse waste were also used to produce binderless particleboard (Hashim et al., 2012; Stanton Greer et al., 2008; Widyorini et al., 2005). There was also a study of coir fibre and wheat straw in the production of particle boards (L. Zhang & Hu, 2014). Banana pseudostems and leaf fibres were used widely as reinforcement material of polymer composites, and some of them were applied in automotive industries (Baharin et al., 2016; M. Ramesh et al., 2014; Patil et al., 2011; Zainudin, 2009; Herrera-Estrada et al., 2007).

2.4.3 Banana cultivation in Malaysia

Banana is an edible fruit, produced the large herbaceous plant with leaf sheaths overlapping which form trunk like pseudostem. The most consumed banana species came from the family of *Musa Acuminata* and originated from Eastern Asian region (Malaysia and Japan) and India, and some of them were linked to Africa region (Mohapatra et al., 2010).

Banana growth starts from rhizomes, the structure of a plant that also called as "corm" as shown in **Figure 2.6**. The banana plant is often mistaken as a tree because the present of the false stem which is also called as a "pseudostem". Moreover, banana pseudostem has very high water content about 90% (Feriotti & Iguti, 2012). The other parts of the banana plant included leaf, sucker, fruit, and inflorescence (**Figure 2.6**).

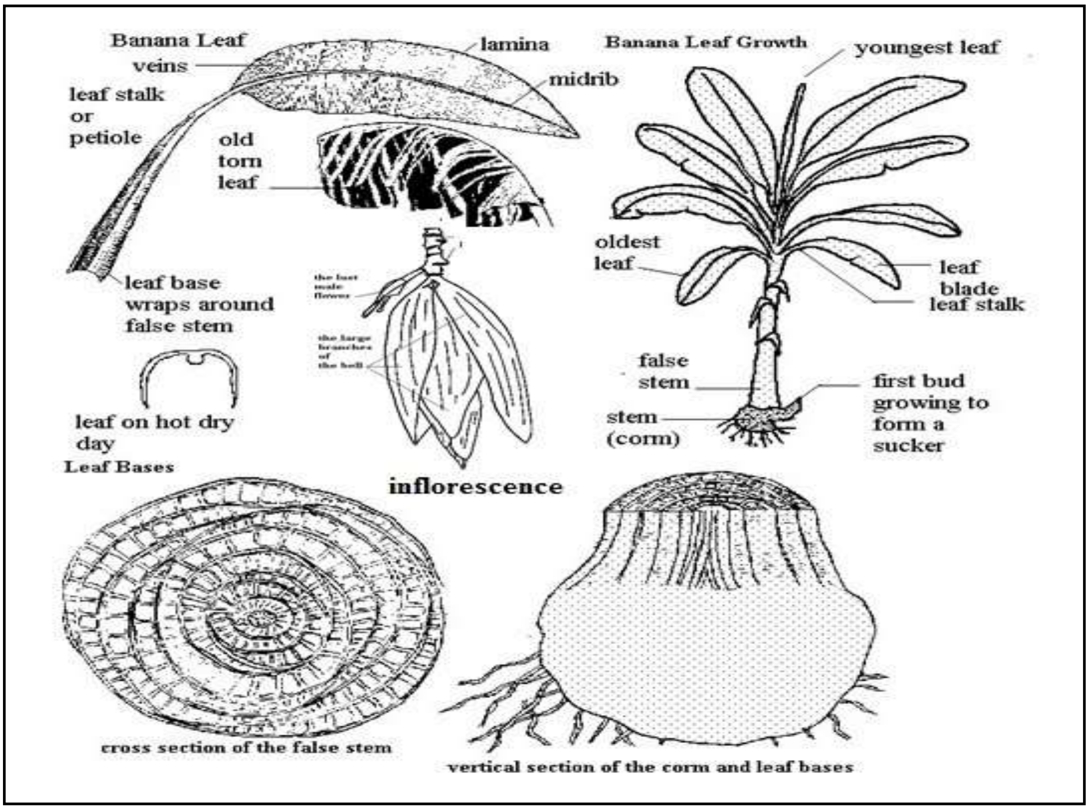

Figure 2.6: Banana tree structure (Elfick, 2014)

Normally banana plant height about 2 to 9 meters tall at maturity and differ for each species and environment (Nelson, 2006). A banana plant took about 9 months to grow and produce a bunch of banana fruits. The mother plant produced baby plants called suckers, and a mother plant could produce between 2 to 6 suckers. Suckers were generated from the main rhizome and growing to produce new banana trees. This process was repeated until the main rhizome dies.

According to the United Nations Food and Agriculture Organization (FAO), there are more than 130 countries that produced banana in the world, and banana fruit is one of the largest fruit crops in the worlds. In 2014, the total global export for banana was worth $11millions dollars (Latina, 2016). Meanwhile, India is the pseudostem producer of banana in the world with the total production of 27 millions of tonnes in 2013 (FAO, 2016).

In Malaysia, banana is the second most widely cultivated fruits, covering about 27,296 hectare and total production of 342,061 metric tonnes in 2015 (Unit Perangkaan, Bahagian Perancangan, 2015). After harvested for their fruit, banana plants produced enormous biomass waste. Usually, banana pseudostems was left to rot in the soil at the plantation as fertiliser or mixed with other wastes to make animal feed. Banana leaves have been used traditionally as food packaging materials or as plates or for lining cooking pit and became waste afterwards.

The increase in banana tree waste, especially their pseudostem waste can cause the greenhouse effect that could contribute to global warming. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the by-products from waste composting. Proper management and maximum utilisation of banana pseudostem waste, such as biocomposite production, can help to reduce the greenhouse effect.

2.4.4 Physical and mechanical properties of banana

Properties of fibre are crucial to determine the performance of the end product for application purpose. It is a main criterion during the fibre selection. Usually, the fibre selection determined by the physical and mechanical properties of fibre, and properties of raw materials would affect the properties of the composite end product.

Jayaprabha (2011) stated that 96% of banana pseudostem fibres consisted of water moisture, which made the dry matter was very low. From the **Table 2.2**, it can be seen that banana pseudostem fibre has low microfibril angle as compared to coir fibre. The small microfibril angle resulted in the increase in strength and stiffness while large angle resulted in increase ductility. Tensile strength was reported to increase with decreasing microfibril angle (Donaldson, 2008). Low microfibril angle exhibited a bigger gap of tensile strength.

Table 2.2: Physical properties of different natural fibre (Satyanarayana et al., 1990)

Fibre	Density (kg/m^3)	Length (mm)	Width diameter (μm)	Microfibrillar angle
Banana pseudostem	1350	0.9-4	80-250	10±1
Coir	1150	0.3-1.0	100-450	30-40
Pineapple	1440	3-9	20-80	8-14
Sisal	1450	0.5-2	50-200	10-22

The length of fibre was vital to determine the strength and stiffness of composite produced. The longer the fibre, the more cellulose and lignin content, hence the increased stiffness, resulting in lower elongation (Tomczak et al., 2007). Based on the **Table 2.2** banana pseudostem had longer fibres as compared to sisal and coir fibre.

A lignocellulosic material from banana pseudostem fibre was known as bast fibre, with relatively good mechanical performances. In the composite industries, physical and mechanical properties have always been important to meet the requirement for different applications. The mechanical properties of banana pseudostem such as tensile strength were observed to reduce significantly with increasing fibre diameter as reported previously by Munawar et al. (2007).

The diameter of the fibre the reported to be reversely correlated to the tensile strength of fibre (Tomczak et al., 2007) because the structural parameter such as lumen and microfibril angle would also change as the diameter structure changes.