CONDUCTIVITY AND MORPHOLOGICAL CHARACTERISTICS OF UNTREATED AND ALKALI TREATED NATURAL FIBRE REINFORCED LLDPE-NR POLYMER COMPOSITE

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In Loving Memory of

Achipillai

K.Rajoo

Puvaninthiran

This humble work is dedicated to my family,

My beloved mother
Selvamany Sabapathy

My beloved father
Sunthrasakaran Palanisamy

My beloved brother
Rhubbindran

My well wisher
Venoogopal Nair

My friends

Dedicated in thankful appreciation for your support, encouragement and best wishes

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ABSTRACT

Polymer nanocomposite has been actively explored in dielectric insulation studies due to its exceptional electrical properties exhibited by these materials. However, inferior properties of polymer biocomposite which is the hydrophilic properties causes less attention in dielectric insulation field. Besides that, the natural fibre waste could be used for a good cause that contributes to Sustainable Development Goals (SDG). Hence, this research is aimed to study the polarization current, depolarization current and conductivity of linear-low density polyethylene (LLDPE-NR) with three different types of natural fibre as filler which are empty fruit bunch (EFB), oil palm frond (OPF) and pineapple leaf fibre (PALF). The samples were fabricated with LLDPE-NR (80:20) as the matrix and compatibilizer by varying the percentage of EFB, OPF and PALF fibre (2.5%, 5%, 7.5% and 10%). The fibres were pre-treated for 6 hours with 5% of sodium hydroxide solution (NaOH) under room temperature. The sample were then fabricated with treated and untreated fibres to assess the difference thoroughly. Moisture absorption test (ASTM D570) was presented for degradation effect. Morphological tests (FESEM, EDX and FTIR) were conducted to monitor the effect of alkali treatment on the fibres and the physical structure of the polymer biocomposite. Result obtained indicates that samples that consist of alkali treated EFB, OPF and PALF exhibits lesser agglomeration compared to sample with untreated fibres which indicates better adhesive properties. The conductivity of each sample was measured using Polarization and Depolarization Current (PDC) testing values. Result indicated 10% of treated OPF fibre is the optimum filler concentration with lowest maximum conductivity value 48.76pS/m under normal condition. Whereas, 2.4% of treated EFB fibre exhibits lowest maximum conductivity with 84.7pS/m under wet condition. In general, treated OPF and EFB fibre performs better when incorporated with LLDPE-NR by exhibiting lower electrical conductivity compared to PALF fibre.

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ABSTRAK

Nanokomposit polimer telah diterokai secara aktif dalam kajian penebat dielektrik kerana sifat elektriknya yang luar biasa yang ditunjukkan oleh bahan-bahan ini. Walau bagaimanapun, kekurangan biokomposit polimer yang merupakan sifat hidrofilik menyebabkan kurang perhatian di medan penebat dielektrik. Selain itu, sisa serat semula jadi yang digunakan menyumbang kepada Sustainable Development Goal (SDG). Oleh itu, penyelidikan ini bertujuan untuk mengkaji arus polarisasi, arus depolarisasi dan kekonduksian LLDPE-NRdengan tiga jenis serat semula jadi yang berbeza yang merupakan tandan buah kosong (EFB), pelepah kelapa sawit (OPF) dan serat daun nanas (PALF). Sampel difabrikasi dengan LLDPE-NR (80:20) sebagai matriks dan penyerasi dengan mengubah peratusan serat EFB, OPF dan PALF (2.5%, 5%, 7.5% dan 10%). Serat tersebut dirawat terlebih dahulu selama 6 jam dengan 5% larutan natrium hidroksida (NaOH) pada suhu bilik. Sampel kemudian dibuat dengan serat yang dirawat dan tidak dirawat untuk menilai perbezaannya secara menyeluruh. Ujian penyerapan kelembapan (ASTM D570) ditunjukkan untuk kesan degradasi. Ujian morfologi (FESEM, EDX dan FTIR) dilakukan untuk memantau kesan rawatan alkali pada serat dan struktur fizikal biokomposit polimer. Hasil yang diperoleh menunjukkan bahawa sampel yang terdiri daripada EFB, OPF dan PALF yang dirawat dengan alkali menunjukkan aglomerasi yang lebih rendah berbanding dengan sampel dengan serat yang tidak dirawat yang menunjukkan sifat rekatan yang lebih baik. Kekonduksian setiap sampel diukur menggunakan nilai ujian Polarization and Depolarization Current (PDC). Hasil yang diperoleh dari 10% serat OPF yang dirawat adalah kepekatan pengisi optimum dengan nilai kekonduksian maksimum terendah 48.76pS/m dalam keadaan normal. Manakala, 2.4% serat EFB yang dirawat menunjukkan kekonduksian maksimum terendah dengan 84.7pS/m dalam keadaan kelembapan. Secara amnya, gentian OPF dan EFB yang dirawat berprestasi lebih baik apabila digabungkan dengan LLDPE-NR dengan menunjukkan kekonduksian elektrik yang lebih rendah berbanding gentian PALF.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Ampere
μ	-	Micro
n	-	Nano
p	-	Pico
V	-	Voltage
kV	-	Kilo Volt
S/m	-	Siemens/meter
DC	-	Direct Current
NaOH	-	Sodium Hydroxide
HV	-	High Voltage
LLDPE	-	Linear Low-Density Polyethylene
NR	-	Natural Rubber
EFB	-	Empty Fruit Bunch
OPF	-	Oil Palm Frond
PALF	-	Pineapple Leaf Fibre
PDC	-	Polarization and Depolarization Current
FTIR	-	Fourier Transform Infrared Spectroscopy
EDX	-	Energy-Dispersive X-Ray
FESEM	-	Field-Emission Scanning Electron Microscope

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the field of electrical insulation for electronics, power electronics and high voltage engineering, polymer composite materials have garnered the interest of researches since 2000. Polymer composite is made up of matrix and reinforcing materials where the matrix serves as an adhesive to hold the filler in place and the fillers act as a reinforcement by providing strength and stiffness. The performance of a polymer composite is improved when the size of a filler is reduced. Hence, recently, polymer microcomposite and polymer nanocomposite, which are made up of micrometer-sized and nanometer-sized filler respectively, have gained increased attention in insulation studies. These studies pertain to electrical properties, physical properties, thermal properties, characterization and sample fabrication of polymer micro and nanocomposite. The reinforcing material used in both microcomposite and nanocomposite is synthetic filler.

Polymer biocomposite is utilized in applications such as floor furnishing, roofing and car interior due to its exceptional benefits. Polymer biocomposites are composite materials comprising of one or more component derived from biological origin [1]. Polymer biocomposite is a material similar to polymer composite except for its reinforcing material which is made of natural fibres. In addition, there are some research that includes coupling agent [2]–[4] or compatibilizer [5] to enhance the compatibility between matrix and reinforcing material. Biocomposite is natural, in contrast to the majority of polymer composite fillers used for insulation purpose, which are synthetic. On top of being low cost, natural fibres have demonstrated many benefits such as high thermal properties, non-toxicity [6], biodegradability, high strength and

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toughness. Thus, natural fibres are a potential replacement to synthetic and glass fibres. As a renewable source, natural fibres requires less energy to process which eases the manufacturing process [7]. Furthermore, few research have shown that polymer biocomposite exhibits of high dielectric strength [6], [8].

Malaysia is rich with natural fibre such as oil palm fibres, pineapple leaf fibres, coir fibre, sugar palm and cotton. In fact, Malaysia is one of the largest exporters of palm oil. The average annual production of palm oil from year 2016 to 2020 is 15.4 million tonnes [9]. In year 2016, the oil palm fibre produced from 85.84 million tonnes of fresh fruit bunch (FFB) amounted up to 36.05 million tonnes [10]. Such mass production of palm oil generates huge amount of waste. This waste is commonly used as fertilizer in plantation and fuel in oil palm plant [11]. On the other hand, we have pineapple leaf fibre (PALF) in Malaysia, which is traditionally used in textile business such as thread production [12]. In some cases, it is just burned and composed by farmers thus contributing to environmental pollution. PALF has been identified by researchers to be a potential good material in paper industry and particleboard production [13].

However, despite the evident benefits of using natural fibre as composite reinforcement, a factor which is often of concern [14]–[17] is its hydrophilic characteristic. All natural fibres naturally absorb moisture. This weakens the adhesivity of reinforcing material (biofibre) and matrix, which in turn leads to poor composite production. Thus, natural fibre is often not desirable to be used in electrical applications. To overcome this issue, modification of fibre characteristics has been studied [18]–[22]. The conductivity of a polymer reinforced biocomposite is highly dependent on the type of fibre, percentage of fibre and the interphase between matrix and fibre. Due to its moisture absorption property, polymer biocomposite has not been widely investigated in insulation study.

When the idea of single polymer composite was introduced in [23], high density polyethylene (HDPE) was used as a matrix. In recent years, due to its distinguished properties, polymer composite has been widely used in applications such as aerospace [24], automobile interior [25], architecture [26], sports recreation [27], pipe and tanks [28] and high voltage applications [29]. Although, polymer composite can be used for insulation purpose, the testing method deployed is crucial to affectively assess the condition of insulator. Polarization and depolarization current is one of a non-destructive dielectric testing methods used to determine the conductivity and

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moisture content of an insulator. In particular, this method is capable of providing the polarization and depolarization current measurement and the dielectric response function of the insulator [30]–[35], without causing damage to the sample. In this research, the influence of water absorption on the polarization current, depolarization current and conductivity is investigated to analyze the degradation effect of the sample with treated and untreated filler. By incorporating treated and untreated natural fibre as filler, the possibilities of sample producing excellent or otherwise result after undergoing water absorption testing is certainly required. In the literature, studies on polymer biocomposite under water absorption test, especially in an insulation. Since, water causes degradation effect when insulation is exposed to outdoor environment, the behaviour of a sample with alkali treated fibre can be studied and compared to a sample with untreated fibre for a potential improvement.

For the past few years, the mechanical properties[36]–[38], characterization and electrical properties of polymer biocomposite [39]–[41] have been widely investigated. Different characteristics of different matrix and reinforcement materials offer a wide range of prospect to be explored. In the spirit, the development of polymer biocomposite using low linear density polyethylene (LLDPE) and Natural Rubber (NR) with different type of natural fibres such as empty fruit bunch (EFB), oil palm frond (OPF) and pineapple leaf fibre (PALF) can be considered. In this study, we investigate natural fibre reinforced polymer composite for the purpose of dielectric insulation. Samples with treated and untreated fibres are studied and compared thoroughly. Beside that, the characterization of the developed polymer biocomposite is scrutinized. After that, the polarization and depolarization current (PDC) method are used to measure the conductivity of polymer biocomposite, allowing better understanding on the performance of polymer biocomposite in relation to insulation.

1.2 Problem Statement

Introduction of natural fibre as a filler is elusive for insulation field due to its hydrophilic characteristic, which affects the adhesive properties of the polymer and natural fibres. Due to this undesirable property, fewer research has been done extensively on biocomposite in insulation studies compared to nanocomposite. The ability of filler to interact with polymer matrix varies based on the type of filler. To

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date, various studies have been done on improvising the interaction between polymer matrix and filler, which depends on the nature of the filler and matrix. The presence of moisture on an insulating material can cause a negative impact on the dielectric properties of the insulator. This is a concern as the addition of natural fibre can lead to moisture absorption in humid condition although in general, it has been proven that the dielectric properties of a material can be improved by introducing a filler to the polymer composite. The effect of water absorption by polymer composite is still far from being well-studied. In this work, Polarization and Depolarization Current (PDC) method is employed to analyze the polarization current, depolarization current and conductivity of the fabricated sample under normal and wet condition.

1.3 Objective of Study

The aim of this study is to develop a polymer biocomposite for high voltage insulation purpose in line with the sustainable development goal (SDG). The objectives of this research are as follows:

1. To synthesize a polymer biocomposite sample with combination of LLDPE and NR with different composition of treated and untreated EFB, OPF and PALF fibre.
2. To conduct morphological studies of treated and untreated raw fibres and sample that consist of treated and untreated fibres.
3. To compute the conductivity of polymer biocomposite from polarization and depolarization current graph under normal and wet condition.
4. To propose the filler percentage with lowest conductivity under normal and wet condition.

1.4 Scope of Study

The scopes of this study are:

1. Pineapple leaf fibre (PALF), oil palm frond (OPF) and empty fruit bunch (EFB) was cleaned and crushed into 100μ ± 20μ.

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2. Compounding of linear low-density polyethylene (LLDPE) and natural rubber (SMR CV 60) with the ratio composition of 80:20. LLDPE-NR was filled with certain percentage of natural fibre.
3. The wt% of natural fibre use was 2.5%, 5%, 7.5% and 10% for both treated and untreated condition.
4. Fabrication of polymer biocomposite was done via compression moulding according to ASTM D4703-03 (170°C, 1 ton pressure)
5. Water absorption test was carried out for treated and untreated polymer biocomposite by immersing the sample into distilled water based on ASTM D570 standard.

1.5 Significance of Study

Based on previous research works, it was found that development of polymer composite studies using synthetic fibre are widely conducted in order to achieve maximum criteria of different types of applications. As a result, this research has opened up the scope on developing natural fibre reinforced polymer as an insulator using suitable testing method. Specifically, the significances of this study could be listed as follows:

1. The findings of this study will redound to the benefit of society considering that natural fibre plays an important role in contributing to the environment today. The greater demand for environmentally friendly or green products justifies the need for less usage of non-renewable resources. Besides that, usage of natural product will help in saving production cost.
2. A polymer biocomposite material for high voltage insulation application was developed. Profound insights regarding the knowledge of determining the significant predictions on polarization current, depolarization current and conductivity under normal and wet condition of polymer biocomposite was presented.

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CHAPTER 2

LITERATURE REVIEW

2.1 Composite

According to the principle of combined action, an enhance property combinations are fashioned by the judicious combination of two or more distinct materials. Composites consists of two or more separate materials that is combined in a structural unit that allows the material to stay distinct and identifiable. Ceramics, metals, polymers and composites are four basic categories of a structural units. The idea of combination between two or more materials usually contributes to strength and compensates weaknesses that individual material possesses. Composites can be classified based on the matrix constituent and reinforcement material used [42]. Classification of composites respect to matrix constituent are divided into polymer matrix composites (PMCs), ceramic matrix composites (CMCs), metal matrix composites (MMCs), intermetallic composites (IMCs) and carbon-carbon composites (CCCs). Figure 2.1 displays the major classification of composite materials that is categorized based on matrices [42], [43].

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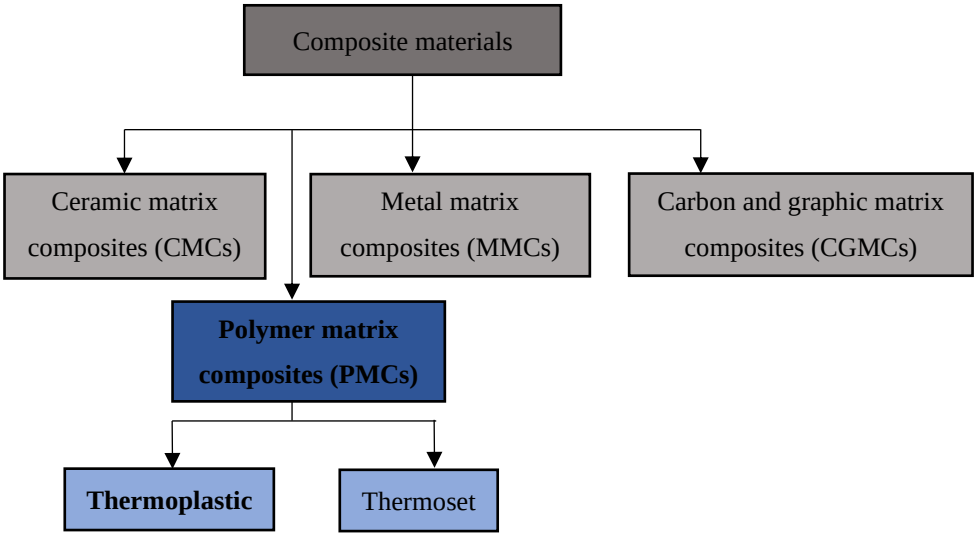

Figure 2.1: Classification of composites based on matrices [42], [43]

The classification of composite respect to reinforced materials can be divided into three groups such as laminar composite, fibre reinforced composite and particulate composite. Figure 2.2 shows the classification of composite based on reinforcing material [44]. Reinforcing materials offer additional purpose of tensile strength, stiffness, heat resistance and resistant to corrosion. A composite acquires a premium feature as the reinforcement material embellishes the matrix which owns a stronger and stiffer characteristic which is capable of changing the failure mechanism to an advantage. Certain factors that contribute into producing extraordinary composite have taken into account by researcher, engineer and scientist. Figure 2.3 illustrates the schematic representation of dispersed phase that plays an important role in producing different types of composite [44]. The relative amount of constituent phase and geometry of dispersed phase forms a composite material. Dispersed phase represents the characteristic of reinforcing material such as fibre length, orientation, size and distribution. Furthermore, researcher reported that the randomly oriented filler has the tendency to manipulate the electrical conductivity and mechanical properties of the polymer composite. It is more applicable to applications that enhances percolation threshold of the of a composite material [45].

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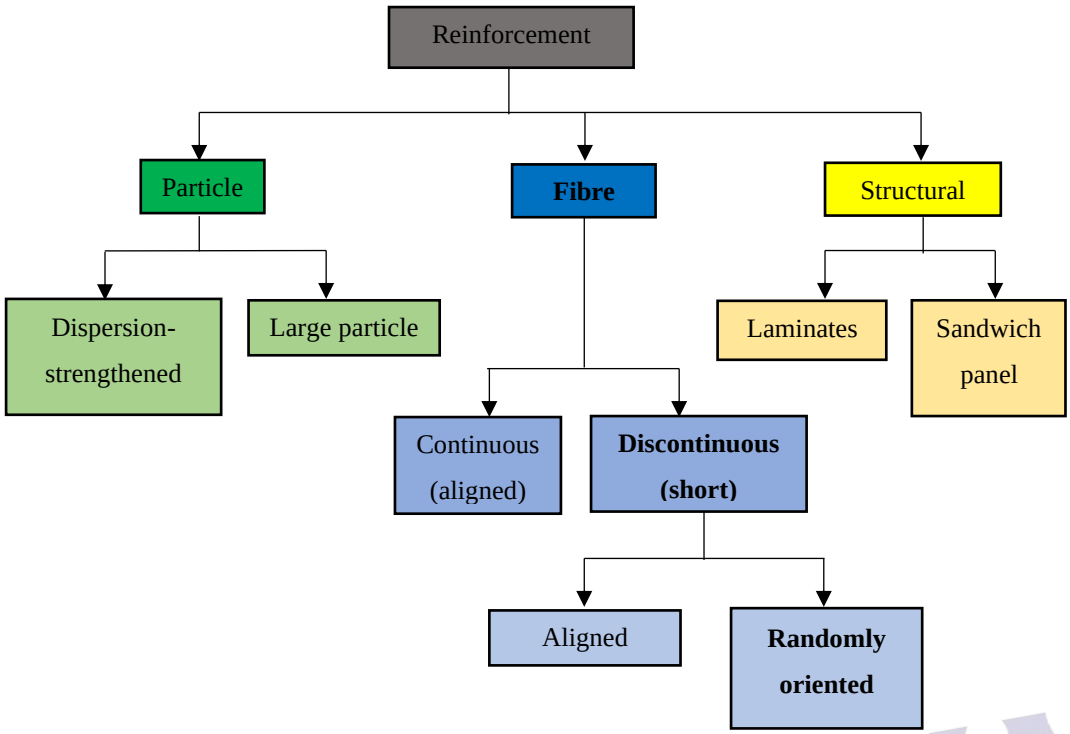

Figure 2.2: Classification of composites based on reinforcing material [44]

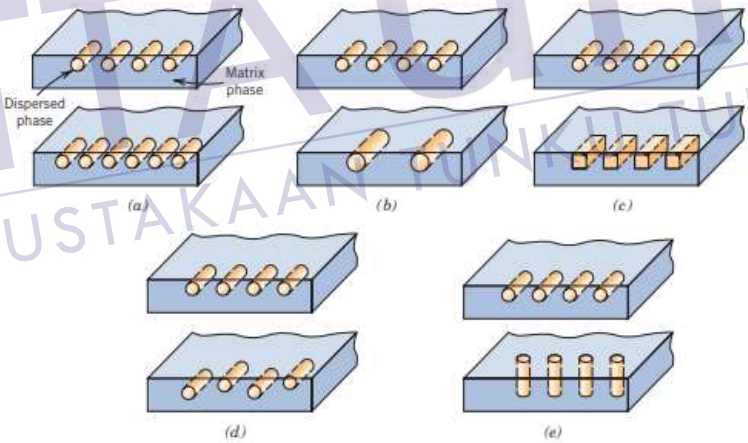

Figure 2.3: Representation of reinforcing fibre characteristics: (a) concentration, (b) size, (c) shape, (d) distribution and (e) orientation [44]

2.2 Polymer Composite

Polymer composite studies have gain attention due to stronger, stiffer and lighter compared to unreinforced polymers [46]. Reinforcing material used in polymer composite studies are usually synthetic fibres. Only recently research on natural fibre have overlook synthetic fibre due to low density, low cost, acceptable strength

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properties and biodegradable [47]. Polymer biocomposite is a combination of natural fibres and matrix with addition of compatibilizer and coupling agent. Matrix can be classified into fully degradable and partly degradable that is shown in Figure 2.4 [48]. Polymer biocomposite acquire several characteristics such as flexibility during processing, low cost, highly specific stiffness that attract manufacturer from engineering, medical and pharmaceutical area. Polymer biocomposite is being implemented in many industries such as automotive [49], tissue engineering [50], aerospace application [51], food packaging film [52] and many more. Hence, current study is focused on developing polymer biocomposite material as high voltage insulation.

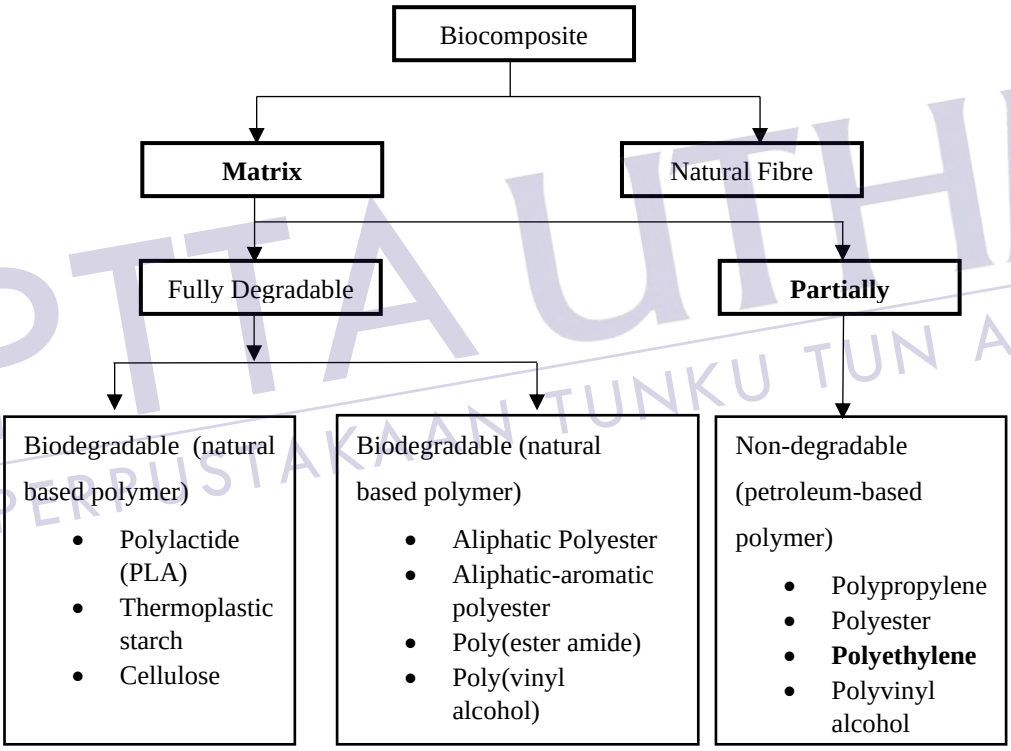

Figure 2.4: Classification of biocomposites [48]

A few research on insulation studies using polymer biocomposite concept has been reported lately. However, most of the studies involved insulation for building applications and thermal conductivity of insulation. S. Sair *et al.* investigated the thermal and acoustic material for building applications using alpha fibres and polyurethane as matrix. They found that 20% of alkali treated alfa fibre exhibits the best mechanical properties, thermal and acoustic insulation [53]. Similar study was

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carried out by researcher [54] in order to investigate the water absorption, thermal insulation and mechanical properties by hybridization of groundnut shell and rice husk. It was found that, higher content of rice husk and smaller filler size shows low thermal conductivity properties. The electrical properties of polymer biocomposite of electrical insulation emphasizes on temperature, density, dielectric constant and dielectric loss was reported by Temp [55]. It was found that, the density of a pure plastic can be increase by adding fillers resulting in increase of material strength. Nevertheless, the absence of plasticizer can cause the material to be brittle. Besides that, alkali treatment can reduce the water absorption rate of material resulting in lower dielectric constant value. Unfortunately, most of the research on polymer biocomposite were focused on mechanical properties of the materials only.

2.2.1 Polymer matrix

Linear-low density polyethylene which falls under thermoplastic category function as a matrix in a composite. Matrix play an important role in holding the fibres and transfer external loads to internal reinforcements [17]. Matrix can be divided into four group shown in Figure 2.5 [42]. Various field has implemented LLDPE material as a result of good processability and their low cost [56]. LLDPE is a significant linear polymer with considerable numbers of short branches. Ethylene with short-chain alpha- olefins for example 1-hexene, 1-butene, and 1-octene are copolymerize to produce LLDPE. The physical properties of LLDPE reported by several researcher was presented in Table 2.1.

Furthermore, by using LLDPE, annealing of the fibres and partial melting could be avoided during composite fabrication owing to low processing temperature (130°C) [36]. Researchers have reported that LLDPE acquire higher melting point and thermal resistance compared to LDPE [52]. For the past few years, researchers are exploring new sources of insulation as an alternative to XLPE [57]. For instance, improvement in development of polymer composite in order to achieve optimum electrical properties has been carried out by few researchers. Likewise, investigation on electrical properties EVA/LLDPE blends proves that blending both material reduces the electrical percolation threshold and varies the conductivity value which is suitable for semi-conductive screen material [58]. Journal reported on blending

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between LLDPE and natural rubber (NR) enhance the electrical properties especially in erosion resistance and electrical tracking [59]. Other than that, treeing phenomena for combination of LLDPE and HDPE presents a better aging-retardance properties [57]. However, based on the findings, LLDPE when mixed with different material and composition tend to produce different characteristic that suits respective application.

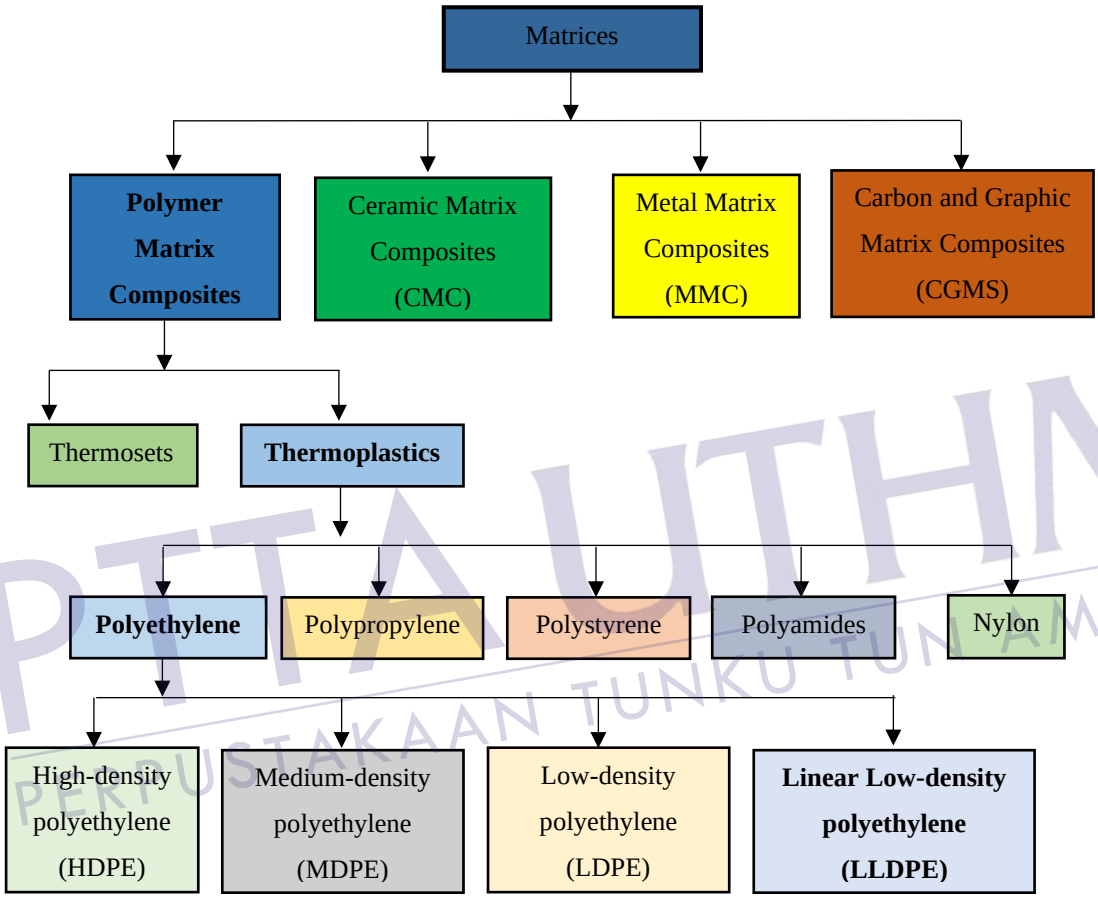

Figure 2.5: Type of matrices [42]

Table 2.1: Physical properties of LLDPE [56]

Physical Property	LLDPE
Density (g/cm^3)	0.930-0.934
Thermal Conductivity W/(m K)	0.32
Volume resistivity/Ω·cm	$\geq 10^{16}$
Dielectric constant	2.10
Tensile Strength/ MPa	25.1

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2.3 Natural Fibre

Replacement of synthetic fibre to natural fibre and fully fossil-based to fully bio-based plastics is due to high cost, pollution, non-biodegradable characteristics. Besides that, the purpose of introducing natural fibre as a biocomposite enhances the usage of environmentally friendly materials. Ideas on utilizing more natural fibres and biopolymers in many research is to provide alternatives for petroleum-based resources that is depleting. The natural fibre as reinforcing fibre that is derived from renewable resources impart favourable environmental benefits. In order to overcome the environmental problem caused by traditional composite such as carbon, glass or aramid fibres, polymer biocomposite is introduced to be adapted to the environment [61].

Growing interest on development of natural fibres reinforced polymers has received considerable attention owing to several advantages for instance low cost, low density, eco-friendly, non-toxicity, good insulation property [63] and renewable in nature. Natural fibre can be classified according to their origin. Demand on natural fibres such jute, flax, oil palm, pineapple leaf fibre, coir, hemp, banana, flax and hemp has been the centre of attention of the researches in recent years. Natural fibre are plant based which are lignocellulosic by nature and consist of lignin, cellulose, hemicellulose and wax [64]. Natural fibres can be divided into three group which is leaf, bast, seed and fruit origin [61].

Figure 2.6 shows the classification of natural fibres [65]. Being one of the largest producers of palm oil, South East Asia, Indonesia and Malaysia in encounter problems in disposing the empty fruit bunch cellulose fibres and thus, it is of interest to convert the waste into useful product [63]. However, the main drawback of biofibres is their hydrophilic nature [17], [66]–[69]. The compatibility of hydrophobic polymeric matrix and hydrophilic natural fibre reduces during composite fabrications. Another disadvantage of natural fibres is that it is subjected to work under low temperature because it may damage/degrade and emit volatile gasses that possibly affect composite properties. Even though there are possibilities for fibres to be processed at higher temperatures under short period of duration, most of the fibres are best processed under 200°C [61]. Many researches regarding factors that affects the performance, methods of producing and different types of application of polymer

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reinforced natural fibre have been carried out but till present date there are still studies reporting on enhancing the performance of polymer biocomposite.

Natural fibres are the core to many products that being discovered in recent years. The advantages of natural fibres are that sustainable, low cost, low density, high specific strength and renewable. Natural fibres intrinsic characteristic has been a drawback as it is high in moisture absorption, poor wettability and incapability with some of the polymeric matrices [69]. Biofibres are made of three major constituents such as lignin, cellulose and hemicellulose. The percentage of cellulose varies according to different species and age of the plant.

Cellulose is a hydrophilic glucan polymer consisting of a linear chain of 1,4-β-bonded anhydroglucose units which contains alcoholic hydroxyl groups. The chemical structure of cellulose consist of three hydroxyl group shown in Figure 2.7 [70]. Intramolecular hydrogen bond is formed within the cellulose macromolecules by two hydroxyl group. Whereas, the rest form intermolecular hydrogen bond within the remaining cellulose molecules [17], [61] . Although, cellulose function as a repellent to hydrolysis, strong alkali and oxidizing agent, possibilities of cellulose to degrade under strong concentration of chemical treatments are expected [58].

It was also reported that all the natural fibres that are hydrophilic in nature consist of 8%-12.6% moisture content [61]. Degree of polymerization varies in a natural fibre even though the chemical structure of cellulose from different natural fibres is the same. The mechanical properties of a fibre are significantly related to DP. Cellulose of different types of fibre has its own geometry that defines the mechanical properties of their respected fibres [64].

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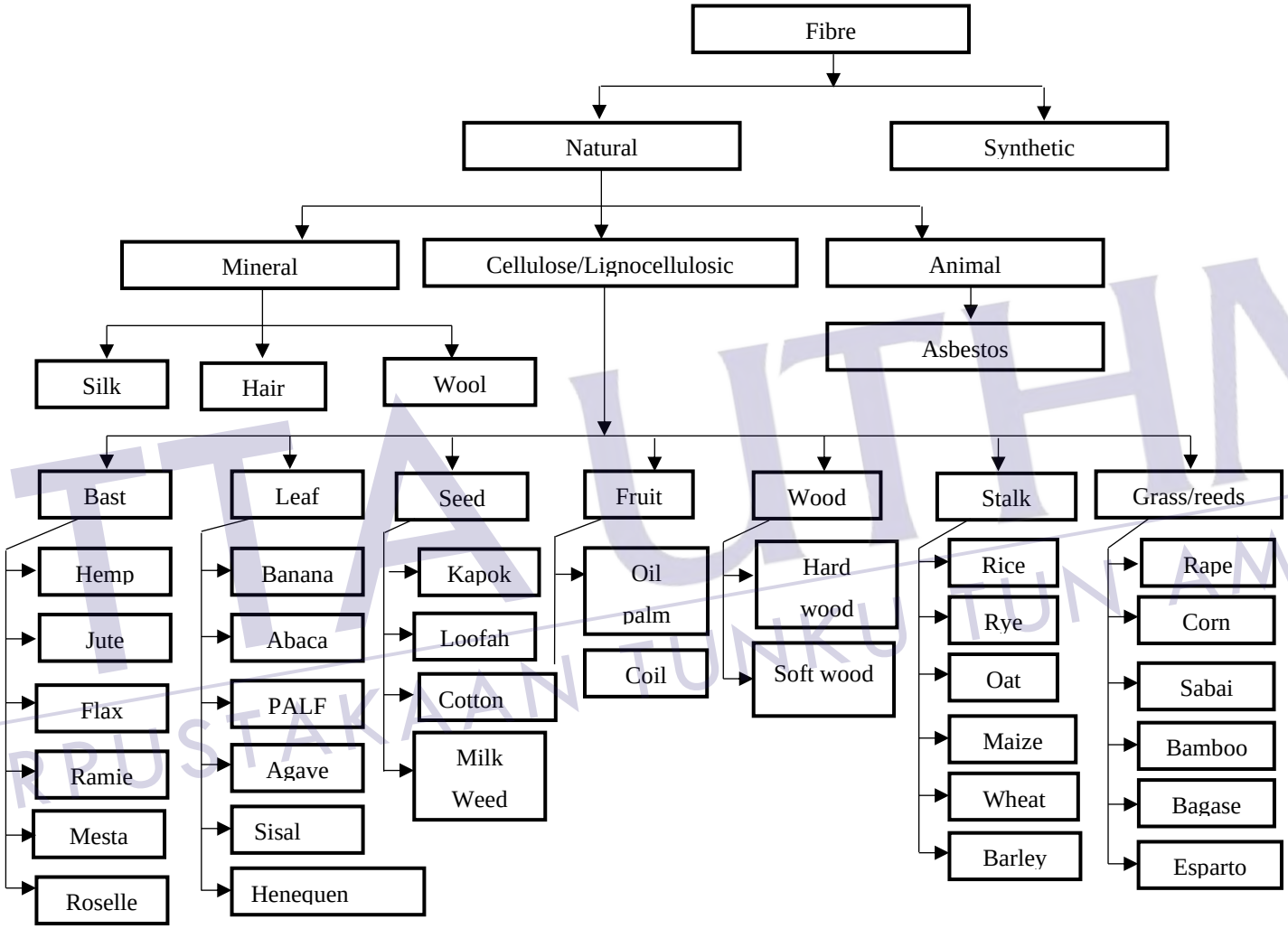

Figure 2.6: Classification of natural fibres [65]

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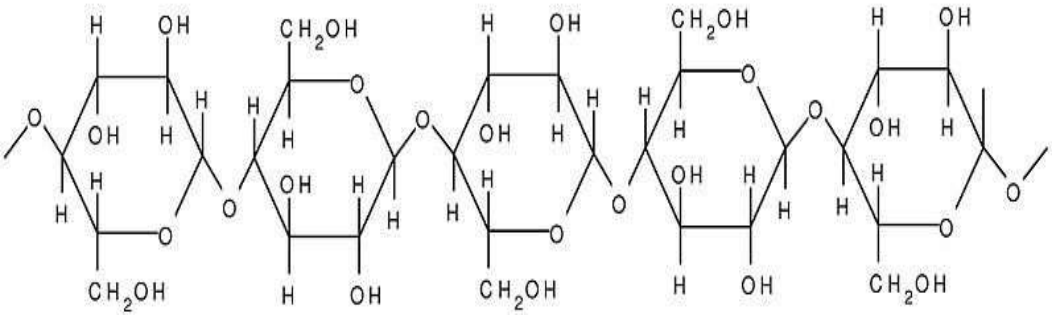

Figure 2.7:Chemical structure of cellulose [70]

Lignin consist of high carbon and low hydrogen which is highly unsaturated and aromatic in character [60] [61] . Lignin contributes structural support to the plant. Lignin is a complex hydrocarbon that assist on the transportation of water and gives rigidity to the plant. Whereas, hemicellulose plays major role in moisture absorption followed by the crystalline cellulose, nanocrystalline cellulose and accessible cellulose. Hemicellulose are lower molecular weight polysaccharides that function as cementing matrix between cellulose microfibrils, forming the main structural component of the fibre cell [58] . It is hydrophilic and be easily hydrolysed by dilute acids and bases. Figure 2.8 displays the structure of biofibre [71].

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Figure 2.8: Structure of biofibre [71]

2.3.1 Oil palm fibre

This section presents detail discussion on the type natural fibres that was used in development of sample for this research. Based on findings, most of the oil palm biomass/ agriculture by-products are produced during replanting, pruning and milling activities, which then is left to decompose in the fields [72]. Oil palm fibres are extracted from oil palm empty fruit bunch (OPEFB), palm kernel shell (PKS), oil palm frond (OPF), oil palm trunk (OPT) and mesocarp fibre (MF). The biomass produced from an oil palm tree is 90% meanwhile palm oil produced from the tree is only 10% [73]. Oil palm is lignocellulosic which consist of cellulose, ash, hemicellulose and lignin.

Oil palm frond are can be obtained in large quantity during the harvesting of fresh fruit bunches. Oil palm frond consist of carbohydrates and lignocellulose [72]. Oil palm frond consist of high hemicellulose content. Whereas, oil palm EFB has the highest amount of cellulose percentage which contributes in high tensile strength and young modulus. Table 2.2 depicts the chemical composition of oil palm fibres. Empty fruit bunch is extracted from the sterilized fresh fruit bunches that undergoes steam treatment at 294 kPa for an hour [14].

Oil palm empty fruit bunch has been utilize in many research to produce roofing material [74], cement board [75], pulp production [76], energy absorption applications [77] and etc. Many studies have been reported on oil palm fibre-based hybrid composite in order to exhibit value added properties of different applications. Utilization of oil palm fibres can be focused on developing insulator as it is a poor conductor. This is because the microstructure of oil palm fibre consist of air gaps [78].

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Table 2.2: Chemical composition of oil palm fibres

Biomass Type	Lignin (%)	Cellulose (%)	Hemi Cellulose (%)	Ash (%)	Moisture Content (%)	References
Empty fruit bunch	29.20	23.70	21.60	7.54	-	[79]
	34.3-35.9	27.3-29.3	36-37.2	-	-	[80]
	18.10	59.70	22.10	4.30	-	[81]
	30.45	22.24	20.58	3.45	5.18	[82]
	-	-	-	4.00	6.00	[83]
	25.60	38.70	31.00	-	-	[84]
Oil palm frond	29.50	40.01	30.78	0.24	13.84	[85]
	15.40	44.00	30.40	4.10	-	[86]
	19.70	-	-	1.74	23.95	[87]
	-	-	-	4.00	12.00	[83]

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2.3.1.1 Electrical properties of OPF and EFB

In this section, recent study related to electrical properties of OPF and EFB was discussed. Dielectric characterization of oil palm fibre reinforced polycaprolactone-nickel oxide composite at microwave frequency investigated reported that high percentage of EFB leads to low permittivity value [88]. In addition, complex permittivity of EFB investigated by researcher [89] indicates that complex permittivity decrease as the frequency and fibre size increase because of high movement of polar molecules dipole and orientation polarization. Besides that, structural and dielectric properties of polyurethane palm oil filled with empty fruit bunch was studied by researcher [90]. It was proven that the composite exhibited stable dielectric properties with respect to frequency and minimum dielectric anisotropy. They have also explained that the percentage of filler could affect the loss factor and dielectric constant of a composite. The dielectric properties and microwave heating of oil palm

biomass was investigated by [91]. It was proven that dielectric constant of oil palm frond is lower than oil palm shell with 1.99 and 2.76 respectively.

Meanwhile, research on oil palm frond for thermal insulation proves that 20%-40% of fibre reduces the thermal conductivity. Besides that, journal has also reported that density of a material is crucial properties in determining the thermal conductivity of a material [92]. Other review study related to insulation board made of empty fruit bunch and oil palm frond conducted by [93] highlights that both material displays a comparatively low thermal conductivity with 0.033-0.037 W/mK and 0.034-0.038 W/mK respectively. This is because both fibres displayed low density and also large number of spaces in the void impeded heat transfer. Thermal conductivity varies according to volume fraction, fibre type and orientation of fibre reinforced composite [94]. Journal reported that thermal conductivity of oil palm fibres is lower compared to jute fibres with 0.2688 W/mK and 0.2976W/mk respectively. Up to date, studies according to electrical properties of oil palm frond and oil palm empty fruit bunch are limited and unexplored.

2.3.2 Pineapple leaf fibre (PALF)

Pineapple leaf fibre (PALF) is one of the waste materials that has been cultivated in agriculture sector for many decades especially in Malaysia as well as Asia. Pineapple also known as Ananas comosus is one the most essential fruits in tropical region after banana and citrus [95]. PALF is made of mostly a polysaccharides and lignin and other compound such as pectin, fat, wax, colouring matter, uronic anhydride, inorganic substances, and pentosane [15]. PALF also comprise of 70–82% of cellulose content and high degree of crystallinity which in return produces excellent mechanical and physical properties such as tensile strength (400–1600 MPa) and modulus (59 GPa). Chemical composition of pineapple leaf fibre is as shown in Table 2.3.

Nowadays, most of the research has been focusing on replacing glass fibre to PALF especially in building materials due to cheap cost. Profound research was conducted in order to discover the ability of PALF to bond with polymer composites to discover the potential applications [96]. Pineapple leaf fibre (PALF) has been in the limelight in material field because it exhibits high specific strength and stiffness. The fibres are made up of a vascular bundle system present in the form of bunches of

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fibrous cells represent a ribbon-like structure which are obtained after mechanical removal of all the epidermal tissues. It was also reported that PALF is of fine quality, and its structure is without mesh and can be extracted into nanofibers thinner than fibres from bacterial cellulose (BC) and tunicates [97].

Table 2.3: Chemical composition of pineapple leaf fibres

Klason Lignin	Cellulose	Hemi cellulose	Holo cellulose	Ash	Moisture Content	References
8.31	66.74	17.45	-	0.71	9.40	[98]
10.50	73.40	-	80.50	2.00	-	[99]
4.20-4.90	67.65-70.98	11.35-15.34	-	0.63-0.95		[100]
5.00	75.20	-	-	-	5.00	[101]
4.40	69.50	-	-	0.90	-	[102]
2.88-4.04	78.22-83.72	10.96-13.66	-	-	10.04-11.00	[96]
5-12	70-82	-	-	-	11.80	[60]

2.4 Compatibilizer

Compatibilizers promotes the tendency of improving the bond between the matrix and filler. In most case, matrix and fillers have difficulties blending due to different physical properties resulting in immiscible composite. Thus, introducing compatibilizer in polymer composite helps to improve the adhesive, morphological and physical properties of the material. They are compatible with one of the phases, these molecules tend to concentrate at the interfaces and stabilize them thus allowing finer dispersion of mutually incompatible pairs. In this research, Natural Rubber SMR 60 was employed as a compatibilizer. Wan Yunus *et al.* [103] stated that natural rubber SMR CV 60 blend exhibits outstanding elasticity, excellent processability and high strength.

Mechanical properties of natural rubber compound from different origin was investigated by Shuhaimi *et al.* [104]. They compared four different types of natural rubber from four different countries which is SMR CV60, STR 5L, SVR 3 and SCR L from Malaysia, Thailand, Vietnam and Cambodia respectively. The tensile properties and tear strength after aging 4 days and 7 days reported highest for natural rubber SMR

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CV60. Furthermore, the effect of compression on SMR CV60 and epoxidized natural rubber 25% was compared in journal [105]. They found that the presence of natural rubber reduces the damages that was caused by compression.

2.5 Factors affecting characteristic of polymer biocomposite

2.5.1 Fibre Loading

It has been reported that percentage of filler plays an important role in identifying the outcome of the composite. When investigating the electrical properties of a polymer composite, the fibre percentage act as a constituent in categorizing whether it turns out to be an insulator or conductor. Journal reported that increase in fibre loading, increases dielectric constant of composite which was more significant during low frequency [15], [106]. This is because at high frequency, the molecular vibrations are high and hence complete orientation of dipoles does not take place and therefore the dielectric constant decreases as frequency increases in all case. The dielectric constant, dissipation factor, conductivity and loss factor increases as fibre content increase [106].

Besides that, increase in fibre loading increases the water absorption rate [4] and reduces tensile strength [107]. Researcher [108] stated that increased in coconut shell powder (CSP), decreases the elongation at break of PLA/CSP biocomposite and tensile strength. However, it increases the elasticity and the thermal stability. Journal reported that increase in PALF content in PALF/HDPE composite decreases the tensile strength of the composite [109]. Moreover, dielectric properties of hybrid natural fibre composite using 10%- 30% of jute and bamboo has been reported by researcher [16]. It proves that the dielectric constant value increases as the percentage of fibre increase. This is because presents of polar groups in natural fibre leads to increment in orientation and interfacial polarizations.

Meanwhile, a review on electrical properties of natural fibre reinforced composite proves that the moisture content in a fibre increases the conductivity of the composite. Hence, higher percentage of fibre in a composite increases the conductivity of the composite [110]. Similarly, dielectric, thermal and magnetic properties of OPEFB fibre-polycaprolactone composite was studied by researcher [111]. They

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prove that, the permittivity and permeability of a material increase as the filler content increase.

2.5.2 Alkali treatment

The hydrophilic characteristic of natural fibre has been an issue in material studies that needed to be addressed as it causes interfacial adhesion problems with hydrophobic polymer matrix [112]. As a result, the incompatibility of hydrophilic natural fibre and hydrophobic polymer matrix leads to formation of aggregates that weakens the properties of composite. Besides having incompatibility issues, hydrophilic fibres also has the tendency of high water absorption which leads to poor dimensional stability of the natural fiber reinforced composites [113]. The primary idea of alkali treatment is to improve the adhesive property between matrix and reinforcing material. Due to presence of polar groups and hydroxyl, natural fibres exhibit a high propensity to absorb moisture. This significantly leads to bad form of composite development as the adhesive properties of both reinforcing material and matrix deteriorates. The alkali treatment also known as mercerization is one of the surface treatments that aims to breakdown the atoms bonds of some fibre surface groups in order to aid their functionalization [114], [115]. Alkali treatment has the ability to alter the cellulosic molecular structure by changing the orientation of highly packed cellulose order to form an amorphous region [17]. This method uses the most common chemical which is sodium hydroxide (NaOH) in order to remove pectin, oil, wax and other organic compounds [116]. Most of alkali treatment is carry out using sodium hydroxide due to low cost [60]. The reaction of sodium hydroxide with natural fibre (Cell-OH) works as shown below [60]:

$$\text{Cell–OH} + \text{NaOH} \rightarrow \text{Cell}-O^{-}Na^{+} + H_2O + surface\ impurities \qquad (2.1)$$

Surface treatment forms amorphous region by reordering the orientation of crystalline cellulose. During the surface treatment, the hydroxyl (OH) groups react with water molecules and leaves the fibre. On top of that, it eliminates certain portion of lignin, hemicellulose, pectin and wax. By doing so, it increases aspect ratio (l/d) by reducing the fibre diameter [17], [64]. Surface modification by sodium hydroxide

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causes dielectric properties of the composite to be less than the untreated ones owing to reduction in the hydrophilic nature of pineapple leaf fibre. Due to alkaline treatment, substantial portions of uronic acid, a constituent of xylene and hemicellulose are removed. The moisture content decreases as a result of alkaline treatment [15]. Thus, alkali treatment helps in disconnecting the 3D cellulose network that was build up by hydrogen. The rigidity of the fibre reduces after undergoing alkali treatment due to reduction in crystallinity and deformation of the microfibrils alignment. In addition, amorphous region will have changes due to dissolution of its major components in alkali solution. Meanwhile, the presence of wax, pectin, lignin and unwanted impurities are removed by bleaching effects from alkali treatment [108]. Alkali treatment also removes the hemicellulose layer causing the cellular networks to deform subjecting to less rigid and less dense interfibrillar region. Thus, allowing the fibrils to rearrange along the fibre major axis. Stretching the fibre results in better load sharing by the fibrils hence higher stress development in fibre. On the other hand, softening of the interfibrillar matrix adversely affects the stress transfer between the fibrils and, thereby, the overall stress development in the fibre under tensile deformation [6, 109].

While conducting alkali treatment process, immersion duration, alkali solution concentration and solution temperature need to be taken into consideration to make sure the fibres undergo adequate alkali treatment process and to prevent the fibres from damaging. However, the treatment parameter varies according to the type of fibres and specific application set by researcher. Mohd Yussni Hashim *et al* conducted an investigation by varying the immersion time during alkali treatment at specific alkali concentration and immersion temperature on kenaf fiber [117]. The immersion duration was varied at 30, 240 and 480 minutes while the alkali solution concentration was varied at 2,6 and 10 (w/v%) under 27, 60 and 100°C temperature condition. They found that, the density of kenaf fibre increased slightly compared to untreated fibre after undergoing alkali treatment. Besides that, similar trend of increment was noticed in the weight loss of kenaf fibre as the treatment parameter increased. Similarly, study on the effect of alkali concentration (0,2,5 and 10wt%) on morphological and thermal properties of date palm fibres [18]. It was proven that 5wt% NaOH improves the interfacial properties between polyurethane and date palm fibres and thermal resistance. However, 10wt% NaOH treatment has reported damages on the fibre surface. This finding had a good agreement with the work reported by [118]–[120] where 5% NaOH alkali treatment is optimal for most natural fibres.

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Moreover, dielectric properties and electrical conductivity of alkali treated and untreated Roystonea regia was investigated [121]. The fibre was treated with 5% NaOH for 2 hours under room temperature. Result shows that, thermal stability was enhanced and conductivity of alkali treated fibre was lower than untreated fibre. Besides that, the dielectric constant for treated fibre is lower compared to untreated fibre. This is because, the lignocellulosic fibre which consist of 12% of moisture and has tendency of absorbing surrounding moisture was removed through alkali treatment. A similar trend on conductivity and dielectric constant of sisal powder filled polyvinyl alcohol biocomposites was reported as the fibre was treated for 70 hours under room temperature with 5% NaOH concentration [122]. Correspondingly, researcher [123] has also reported on improvement of electrical and thermal behaviour on jute fibre after undergoing alkali treatment. The fibre undergoes sodium hydroxide (NaOH) treatment with 4%, 5% and 6% of NaOH concentration for 2, 4 and 6 h at 20, 30 and 40°C temperature. They found that the interaction between water molecules and polar group in jute fibre was reduced resulting in elimination of hydrogen bonds. As a result, the elimination of water molecules increases the hydrophobicity of the fabric resulting in reduction of orientation polarization. Moreover, the improvement of adhesion properties between fibre and matrix leads to compact structure between jute fabric and resin. In addition, the reduction in conductivity and increased in volume resistivity of the composite was achieved by elimination of void, porosity and irregularities via alkali treatment.

As a conclusion, most of the researcher results show a similar trend of fiber properties after alkali treatment process compared to untreated fiber. However, there are few studies that reported on fibre damages caused by higher alkali treatment concentration. Thus, it is important to further analyse and study on the parameter of alkali treatment to determine behaviour of EFB, OPF and PALF fibre. Table 2.4 shows summary of the effect of alkali treatment on pineapple leaf fibre compiled from previous works.

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Table 2.4: Study on alkali treated pineapple leaf fibre

Alkali Concentration	Temperature	Duration	Findings	References
2%, 4%	Room	1 hour	Tensile strength: 12% and 24% Tensile modulus: 1197MPa and 1284MPa	[67]
2%, 4%	Room	1 hour	Increased thermal decomposition and glass temperature (t_g) No significant improvement in the melting temperature.	[124]
6%	Room	3 hours	Reduction in diameter due to removal of impurities. Improved tensile properties	[125]
5%	Room	1 hour	Showed improvement in tensile strength and Young's modulus.	[126]
0%, 4%, 6%, 8%	Room	1 and 3 hours	Optimum concentration and soaking hour = 6% and 1 hour. Increase thermal stability by 14.32°C. 8 % alkali treatment deteriorates the mechanical properties of PALF by 18%.	[21]
10%	30°C	2 hours	Surface modification treatment performed to pineapple-leaf fibres did not improve mechanical properties of composites because of the formation of agglomeration of fibres inside the composite.	[98]
1%	85°C	1 hour	Decrease in the tensile strength and increase in elongation.	[100]

Oil palm fibres are rich in moisture content due to its hydrophilic characteristic. Journal reported that water absorption rate of oil palm fibre was reduced after alkaline treatment [69]. Researchers reported that alkali treated fibres showed considerable reduction of water uptake and improve the adhesion between matrix and fibre [106], [127]. Hydrophilic characteristic of oil palm fibres affects the mechanical properties of the composite and leads to separation of fibre and matrix after aging [69]. Alkali treatment removes pectin and waxy substances that blocks the reactive functional group and act as a barrier to bond with the matrix [17]. Reported work on alkali treated oil palm fibre-based composites are shown in Table 2.5.

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