EFFECTS OF KENAF FIBRE SURFACE TREATMENT TO THE MECHANICAL PROPERTIES OF RECYCLED POLYPROPYLENE COMPOSITES

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

ABG MUHD FAKHRULLAH BIN ABANG AHMAD

FACULTY OF MANUFACTURING ENGINEERING

2022

DECLARATION

I hereby, declared this report entitled “Effects of kenaf fibre surface treatment to the mechanical properties of recycled polypropylene composites” is the results of my own research except as cited in reference.

Signature :
Author’s Name : ABG MUHD FAKHRULLAH BIN ABANG AHMAD
Date : 30 June 2022

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.). The members of the supervisory committee are as follow:

…………………………………………….

(Ts. Dr. Jeefferie Bin Abd Razak)

ABSTRAK

Polimer yang diperkukuh dengan pengisi gentian semula jadi berpotensi mencipta bahan hijau dengan bahan yang lebih mampan dan mesra alam untuk alam sekitar. Justeru, penyelidikan ini dijalankan untuk membangunkan gentian kenaf (KF) yang diperkukuh dengan komposit berasaskan polipropilena (r-PP) kitar semula. Sifat mekanikal dan fizikal komposit telah ditentukan melalui kajian ini. Gentian semulajadi dirawat dengan larutan NaOH 10% dan larutan NaOH Silane 10% dan dikeringkan dalam ketuhar selama 24 jam pada suhu 80°C. Komposit polimer bertetulang gentian asli (NFRPC) telah diadun menggunakan pengadun dalaman diikuti dengan pengacuan mampatan. Pemilihan komposisi optimum bagi komposit berasaskan r-PP/KF bergantung kepada pemuatan gentian dan rawatan. Oleh itu, dalam kajian ini, pemuatan gentian yang berbeza bagi gentian semula jadi (0, 10, 20, 30, 40 wt.%) dan rawatan (NaOH dan NaOH Silane) dengan saiz 62μm digunakan untuk menyiasat mekanikal, dan fizikal komposit yang direka. Kemudian, morfologi rekah sampel dianalisis dengan pemerhatian mikroskop elektron imbasan (SEM). Pada akhir kajian ini, sampel yang mempunyai kekuatan mekanikal tertinggi akan dicadangkan. KF yang dirawat NaOH telah berjaya dipertingkatkan ciri mekanikal KF, dari segi kekuatan tegangan dan lenturnya. Sampel yang dirawat NaOH 10wt% menghasilkan peningkatan yang luar biasa dalam ciri mekanikal dan fizikal sekali gus menunjukkan rawatan ini telah berjaya meningkatkan sifat KF. Penyelidikan ini amat penting untuk dijalankan bagi menyediakan alternatif yang lebih baik untuk bahan yang lebih hijau yang lebih mampan dan mesra alam dalam penggunaan kehidupan seharian.

ABSTRACT

Polymer reinforced with natural fibres filler potentially creates a green material with more sustainable and eco-friendly alternatives for the environment. Thus, this research was carried out to develop kenaf fibre (KF) reinforced with recycled polypropylene (r-PP) based composites. The mechanical, and physical properties of the composites had been determined through this study. The natural fibres are treated with 10% NaOH solution and 10% NaOH+Silane solution and oven dried for 24 hours at 80°C. The natural fibre reinforced polymer composites (NFRPC) were compounded using an internal mixer followed by compression moulding. The selection of optimum composition of r-PP/KF based composites depends on the fibre loading and treatments. Therefore, in this study, different fibre loadings of natural fibres (0, 10, 20, 30, 40 wt.%) and treatments (NaOH and NaOH+Silane) with the fibre sizes of 62μm were used to investigate the mechanical, and physical properties of the fabricated composites. Then, the fracture morphology of the samples was analysed by scanning electron microscopy (SEM) observation. At the end of this study, samples with highest mechanical strength performance was proposed. The NaOH treated KF had successfully enhanced the mechanical characteristic of KF, in terms of their tensile and flexural strength. The 10wt% NaOH treated kenaf sample has yielded an extraordinary improvement in mechanical and physical characteristics thus suggesting the treatment was successfully enhanced the properties of KF for composites application. This research is significantly important to be carried out to provide better alternatives for greener material that are much more sustainable and eco-friendly in daily life use.

DEDICATION

Dedicated to
My beloved parent, Abang Ahmad Bin Abg Abd Wahab and Nurul Izza Tiong
My appreciated siblings, Dayang Nurfaezah, Dayang Nurshafiqa, Abg Mohd Fathullah, Lau Siew Chui, Abg Mohd Faadhillah and Dayang Nurathirah
My friends, housemates, coursemates for giving me encouragement, motivation, and support, understanding, and also cooperation.

ACKNOWLEDGEMENT

“Bismillahir Rahmanir Rahim”

Alhamdulillah, I expressed gratitude to Allah for providing me with the opportunity to successfully complete this Bachelor Degree Project 1. To my parents, I would like to special thanks for always being there for me, even in the most difficult of situations.

Ts. Dr. Jeefferie Bin Abd Razak, my respected supervisor, deserves special recognition for his guidance and passion in supervising me throughout this project period. His understanding and patience with my shortcomings were greatly appreciated.

Finally, I would like to express my appreciation to all of my friends for their help and suggestions throughout the course of this project. Thank you also to those I didn't mention, each and every one of you who is directly or indirectly assisting me in completing this project. May God bless you and reward you for your kindness in thousands of ways.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

aPP	-	Atactic Polypropylene
ASTM	-	American Society for Testing and Materials
CMC	-	Ceramics Matrix Composites
FTIR	-	Fourier Transform Infrared Spectroscopy
iPP	-	Isotactic Polypropylene
KF	-	Kenaf Fibre
MMC	-	Metal Matrix Composites
NaOH	-	Sodium Hydroxide
NaOH+Silane	-	Sodium Hydroxide and (3-aminopropyl) triethoxysilane
NFRC	-	Natural Fibre Reinforced Composite
PMC	-	Polymer Matrix Composites
PP	-	Polypropylene
r-PP	-	Recycled Polypropylene
SEM	-	Scanning Electron Microscopy
sPP	-	Syndiotactic Polypropylene
UV	-	Ultraviolet

CHAPTER 1

INTRODUCTION

This chapter presents full explanation on the background of the study. The research objectives to be accomplished to solve the stated problem statement, rationale of research, and the thesis organisation are also included. The impact of conducting this study is also comprehensively justified. Besides, this chapter also emphasize the limitation of the study through the scope of work.

1.1 Background of Study

Our world has always been filled with a variety of materials. Materials has evolved through time to become what they are now. Over the millennia, man has dealt with a wide range of materials, from the stone age, progressing through the metal age, and finally the polymer age (Smith, 2019). The shift in material ages occurred as human continue to evolve throughout the future, demand for the improvement of materials to meet current requirements and functions. A polymer, undebatable one of the finest materials ever created due to its distinctive characteristics, has achieved dominance in a wide range of applications. Corresponding to Wang (2011), also stated polymers are undoubtedly one of the best materials ever produced. It was not surprisingly said that the polymer is the material of the century. Polymer alone somehow not able to provide strength and load bearing capability, especially for structural application, due to their limited mechanical properties. Hence, composites are often made by reinforcing polymers with other materials, in order for them to appropriately acquire the required characteristics for ultimate performance in a broad selection of applications. As a result, the creation of polymer composites has continued to remain as one of the most effective ways of influencing the polymeric materials properties. There has been an increasing need for materials that are lighter, stiffer, stronger, and more environmentally friendly, because of the rapid growth in manufacturing industrial sectors. It has become amongst the most promising materials for a diverse applications because of its improvement in characteristics and versatility (Chukov et al., 2019; Sherif et al., 2019; Yashas Gowda et al., 2018).

In conjunction to this, Zampaloni (2007) mentioned that as industry work their way to reduce its reliance on petroleum-derived products, there is a growing need to develop alternative eco-friendly, renewable sources, long lasting sustainable materials to replace existing carbon fibre and glass fibre reinforced composites. Thus, natural fibre reinforced composites (NFRC) have been lately under the spotlight for their development and performance characteristics. Kenaf, flax, sisal, and hemp, are some of the natural fibres that were previously studied as alternatives for non-recyclable fibres. A wide variety of fibres are available at low cost and good ecological traits. Other benefits include the high strength, matching specific toughness properties, low density, ease of separation, reduced tool wear, and easy to fabricate (Mohanty et al., 2000).

Thermoplastic polymer, specifically commercial polypropylene (PP) is used as the matrix for composites applications. The benefits of utilising polypropylene (PP) as a matrix include its low processing temperature and minimal cost which are necessary due to natural fibres' limited thermal stability. PP based composites have gained much attention among eco-friendly polymer composites because of their recyclability (John et al., 2010). The study done by Srebrenkoska (2008) learned that polypropylene composites reinforced with kenaf fibre were less vulnerable to repeated process cycles and their characteristics are remained intact even after recycling. In conjunction with reducing plastic waste worldwide, recycled polypropylene (r-PP) will be significantly reused to fabricate the NFRC.

NFRC has always been difficult to fabricate due to the relatively low processing stability. NFRCs can be manufactured by using conventional production processes, such as vacuum infusion, injection moulding, or compression moulding. Even today, these procedures are extensively used as efficient methods for the manufacturing of high-quality composite materials. However, using these approaches to produce NFRCs requires a thorough understanding of the structural features of natural fibres, which have less mechanical resistance to shear, limited thermal stability, hygroscopic, and lack of homogeneity with standard thermoplastics (Ho et al., 2012). Hence, pre-treatment of NFRCs has always been a critical consideration for improving their processability. Improvement of the interfacial contact between the reinforced filler and the matrix polymer requires chemical treatment and modification of the fibre surface. A direct link between materials and processing, as well as composite qualities, is crucial (Arifur Rahman et al., 2015). As for these studies, the natural fibre specifically kenaf fibre (KF) is chemically treated using sodium hydroxide, (NaOH) solution and sodium hydroxide and (3-aminopropyl) triethoxysilane (NaOH+Silane), solution for the treatment before blending it with the recycled polypropylene (r-PP).

This study aims to explore the effects of KF fillers surface treatment and filler loadings to the resulted mechanical, and physical, properties of recycled polypropylene (r-PP) based composites. The effect of treated and untreated KF was also examined further for the overall performance of produced NFRCs, for several potential structural and multi-functional applications.

1.2 Problem Statement

Plastic pollution has threatened the global ecosystem due to its resistance to degradation and widespread use in the production industry. There are several harmful and environmentally effects of plastic waste in the aquatic ecosystem. Plastic product is a direct hazard to nature and wildlife, with numerous and diverse species having been proven to be harmed by plastic waste (Webb et al., 2013). Hirai (2011), also mentioned that ocean plastic has high amounts of organic contaminants. There have been harmful compounds detected countless times in ocean plastic wastes. The existence of these contaminants heightens the potential risks with wildlife consumption of plastic debris. Moreover, most of these plastics can undergo numerous biomagnifications and may directly threaten public health. These toxic chemicals have been connected with many health problems, including cancer, arthritis, diabetes, neurobehavioral changes, development impairment, and endocrine disruption (Ali et al., 2021; Schecter et al., 2010; Vethaak & Leslie, 2016).

According to Chamas (2020), the rate of degradation of each plastic may varies and the knowledge on the degradation kinetics and mechanisms are still not adequate. The rate of the plastic degradation often differs between several report. But more often, regardless of the insufficiency of scientific data. Media has depicted the expected periods for a plastic bags to decompose is around 500 to 1000 years (Delaney, 2013). While, some media had described that the plastics are non-degradable (Kari O., 2011). However, the type of plastics used in these claims is frequently uncertain, and the environmental factors are not clarified. Furthermore, the method used to deduce the outcome is still unknown. Every one of those variables has a significant impact on degradation rates. Besides that, scientific research on the degradation times of plastics is changing, and approximated lifespans of plastic waste can change drastically based on new evidence (Chamas et al., 2020).

The study of green product development has been performed lots of researchers to overcome the increasing waste that has been contributed mostly by plastic disposal after food and paper. According to Kaza & Yao (2018), the world made a total of 242 million tonnes matrix of plastic waste in 2016 alone, which most of the plastic wastes are contributed by East Asia and the Pacific with 57 million tonnes, 45 million tonnes from Central Asia and Europe, and North America with 35 million tonnes. More research studies are currently focusing on environmentally friendly composite materials such as natural fibres to reduce the world's environmental impacts, carbon footprints, and pollutions. In a sense that the natural fibres are biodegradable, low cost, low density with no toxic traits, good mechanical properties, and widespread availability (Gurunathan et al., 2015).

Commonly, the production of plastics is still depending mainly on fossil-based materials, which is the main cause of the increasing waste worldwide. Hence, replacing the filler part with natural fibres instead of synthetic fibres to develop natural fibre-reinforced composites (NFRC) could help overcome the future problem in managing plastic waste. Although NFRC can reduce the plastic waste produced globally, blending plastic or polymer with natural fibre is not an easy task. Plastic is a hydrophobic material that is water-resistant. At the same time, natural fibres, which are lignocellulosic and contain strongly polarised hydroxyl groups, are hydrophilic by nature and require an accurate chemical treatment to improve bond and compatibility between fibres and matrix (John et al., 2010). There is not much specific research done regarding NFRC blends with the proper ratio to produce the most efficient polymer composites using recycled polypropylene reinforced with natural fibres. Therefore, the idea of considering KF to substitute the filler part in polymer composite to produce new green bio-composites polymer are taken into consideration.

There are several possible problems that will be facing in producing natural fibre reinforced polymer composites. When natural fibre particles incorporated into polymer matrix, it can easily aggregate and agglomerate. Agglomeration could occur during the fabrication of natural fibres filler or during reinforced them into polymers. Agglomeration is a term used to describe strong and dense particle collectives of natural fibres. In addition, agglomeration occurs when particles are loosely combined and can be easily damaged by mechanical pressure (Zare, 2016).

Overall, by considering all these matters, the motivation of doing this research is clearly spelled-out and essential to be further explored. This is because no previous similar study has been detected in the existing literature, specifically about the KF reinforced r-PP polymer composites with an accurate loading formulation and specific surface treatment that has available or obtainable explored.

1.3 Objectives of Research

The following are the research's objectives:

(a) To evaluate the success of surface treatment performed to the kenaf fibre (KF) using an FTIR analysis method.

(b) To study the effects of surface treatment of KF natural fibre added as filler in recycled polypropylene based composites at various filler loadings (0wt.%, 10wt.%, 20wt.%, 30wt.%, 40wt.%) by using several mechanical, and physical testing.

(c) To observe the fracture morphology of KF/r-PP composites by using the Scanning Electron Microscope (SEM) for fabricated r-PP filled composites.

1.4 Scope of Research

The research scopes are as follow:

(a) Develop a polymer-based composites using r-PP as matrix with kenaf natural fibres as a filler through melt blending method by using an internal mixer melt compounding machine.

(b) Characterise the polymer-based composite's various mechanical, and physical properties. The properties that were evaluated are tensile strength, tensile module, elongation at break, flexural strength, density, and moisture absorption.

(c) Study the performance of KF/r-PP reinforced polymer composites categories based on surface treatment types which are untreated, treated with NaOH and treated with NaOH+Silane

(d) Analyse the characteristic of failure mechanism and resulted morphologies of KF reinforced r-PP polymer composites system by using the Scanning Electron Microscopy (SEM) observation.

1.5 Rationale of Research

The rationales of research are detailed as follows:

(a) Green composite product would be developed from this research. This is because, by embedding natural fibre into r-PP, the strength of r-PP based composite might be enhanced. This research analyses how the KF natural fibre could enhance the composite strength when incorporated to the r-PP recycled based materials.

(b) Develop more information and deep understanding about the role of added natural fibre when it incorporates to the r-PP matrix to improve the properties of the fabricated polymer composites.

(c) To gain new knowledge for natural fibre reinforced polymer (r-PP) composite by conducting some related testing (mechanical, physical, and morphological).

(d) To develop an alternative green material that possesses a sustainable solution and high-performance attributes. Kenaf is natural fibre that are biodegradable, and r-PP is waste that are abundantly available in Malaysia. Therefore, a greener way and superior performance green composites material can be developed through this research.

1.6 Thesis Organisation

This research is about to study the effects of KF fillers surface treatment to the mechanical, and physical properties of recycled polypropylene-based composites. In the meantime, the effects of fibre loadings (at 0, 10, 20, 30, 40 wt.%) would also be inspected and evaluated.

The arrangement of the thesis begins with Chapter 1. The first chapter is all about the research’s background, problem statement, objectives, and scope. The second chapter comes next. Chapter 2 is a review of previous related research on polymer, kenaf fibre, and fibres surface modification of the polymer composites. All those criteria must be met in order to create a natural fibre reinforced polymer composite system. The methodology in Chapter 3 describes the entire raw materials that will be used, as well as related manufacturing processes that will be used to produce the r-PP reinforced with KF composites. Aside from that, standard testing procedure according to the ASTM standard will be covered in this chapter. The outcome and discussion were later included in Chapter 4. The fourth chapter is about data analysis and discussion. This section will go over all of the data obtained and gathered from various tests. These will include the mechanical, and physical properties, as well as morphological observations. Finally, the conclusion section, which was included in Chapter 5, brought the thesis to an end. All of the discussion will be concluded and critically summarised in this chapter based on the stated and aimed objectives of this research, together with several recommendation for future improvement.

1.7 Summary

Chapter 1 summarises the introduction of the study, which involves identifying the research's problem statement. The background of the study was also concisely explained, and the research’s objectives are clearly by following the stated scope of study for limitation and boundaries. This chapter also has included the thesis arrangement of the whole thesis. Finally, the significance of research also described in this chapter.

CHAPTER 2

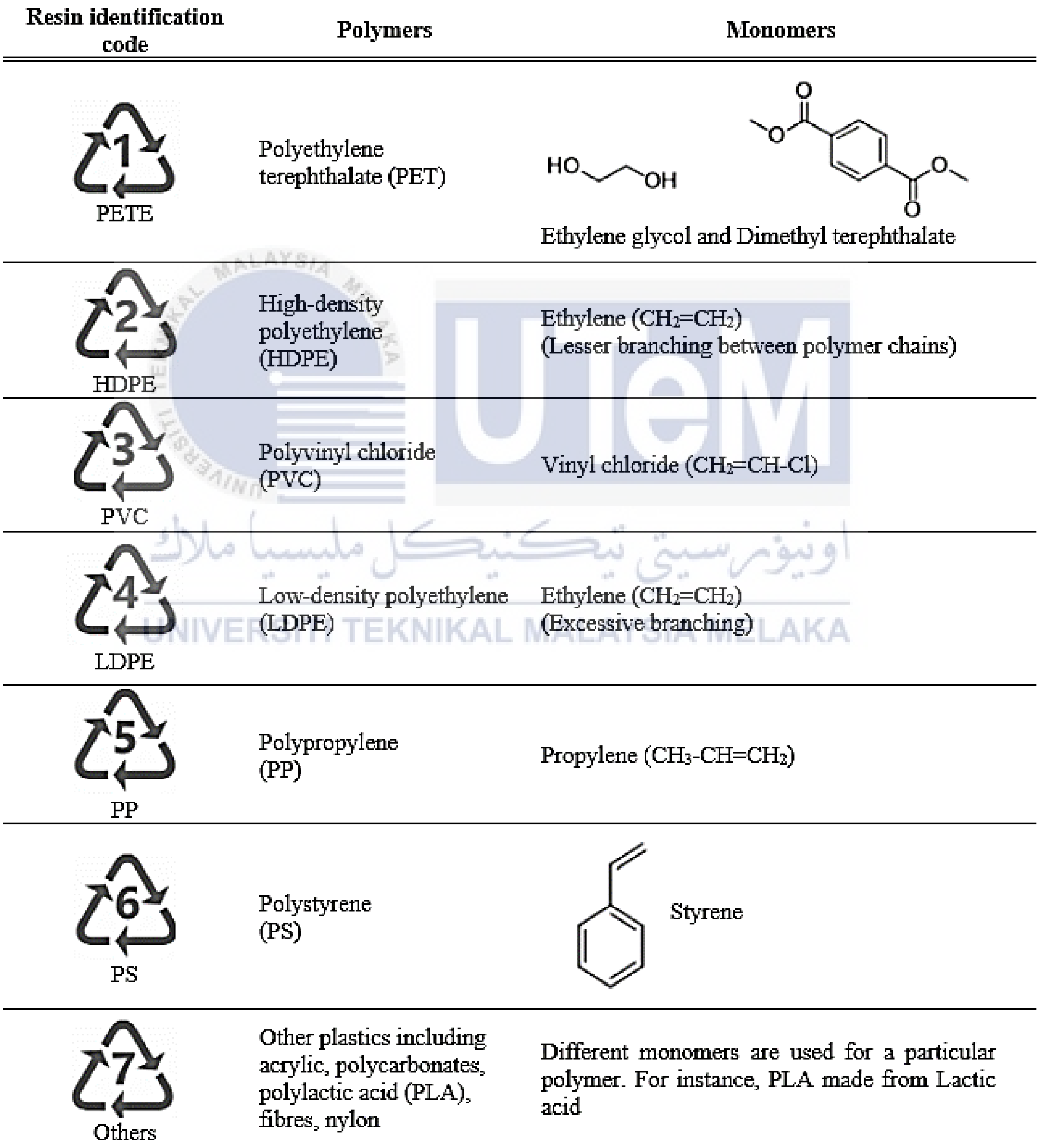
LITERATURE REVIEWS

This chapter were discussed and reviewed the theory, knowledges, and related findings of prior researchers pertaining to this study. The content of this chapter includes the preparation and characterization of r-PP based composites. Therefore, characteristic of polymer (polypropylene) and natural fibres (KF) were throughly discussed in this chapter. Furthermore, the common preparation and fabrication process from previous studies are also described throughout the chapter. At the final part, the summary of previous research is also systematically included.

2.1 Polymer

The term polymer refers to a group of an unspecified number of monomer units. Polymers may be found in a variety of forms in surrounding. From biopolymer, which naturally occurring in the strand of our DNA, to polypropylene, which is exploited as commercial plastic across the globe (Ali et al., 2021). Polymers are not limited to monomers with similar molecular weight, chemical composition, or structural arrangement as one another. Some natural polymers are made up of just one kind of monomer, such as cellulose. The vast majority of natural and man-made synthetic polymers, on the other hand, are composed of two or more distinct kinds of monomers; these polymers are referred to as copolymers (Wang et al., 2011). Polymers may be found naturally in animals and plants, referred to as natural polymers, and they can also be synthetic polymers which are man-made. Different polymers have distinct physical and chemical characteristics that enable them to be used in everyday lives. Polymers are always produced by the polymerisation process, in which their basic parts, known as monomers, combine together to form polymer chains. The sort of polymerisation mechanism performed is determined by the functional groups connected to the reactants. Table 2.1 show the common polymer used on commercial basis, together with the monomers and chemical structures for such polymers (Christopher C. I, 2011).

Table 2.1 Main Polymer types, monomers, and chemical structures (Christopher C. I, 2011)



Resin identification code	Polymers	Monomers
1 PETE	Polyethylene terephthalate (PET)	Ethylene glycol and Dimethyl terephthalate
2 HDPE	High-density polyethylene (HDPE)	Ethylene ($CH_2{=}CH_2$) (Lesser branching between polymer chains)
3 PVC	Polyvinyl chloride (PVC)	Vinyl chloride ($CH_2{=}CH\text{-}Cl$)
4 LDPE	Low-density polyethylene (LDPE)	Ethylene ($CH_2{=}CH_2$) (Excessive branching)
5 PP	Polypropylene (PP)	Propylene ($CH_3\text{-}CH{=}CH_2$)
6 PS	Polystyrene (PS)	Styrene
7 Others	Other plastics including acrylic, polycarbonates, polylactic acid (PLA), fibres, nylon	Different monomers are used for a particular polymer. For instance, PLA made from Lactic acid

According to Gary. E. Wnek (2015), the main of the reasons for polymers' worldwide acceptance and attraction is that they are the most flexible of all engineering materials, with mechanical characteristics are ranging from incredibly strong fibres to soft gels and rubbers. This compatibility is influence by the design flexibility of the repeated unit structure and control over molecular weight or chain length and chain structure. While most polymers have inorganic backbones, carbon backbones for example silicones give another level to material properties.

In the near future, there will be many more polymers synthesised than there are now. Joel R. Fried (2003) in the book of “Polymer Science & Technology”, mentioned that polymers can be categorized into one of the classes depending on their processing properties or the sort of polymerisation technique used. Polymer structure can be used to make more specific classifications. These kinds of groupings are useful because they make it easier to explain attributes.

2.2 Types of Polymers

There are two types of polymers that are commonly used as shown in Figure 2.1, which is thermosetting polymer and thermoplastic polymer (Liu et al., 2015). Thermoplastics are polymers that may be heat-softened to be processed into a chosen shape. By using pressure and heat, thermoplastics wastes are capable of recycled and refabricated. Examples of thermoplastic includes polyolefins, such as polypropylene, polyethylene, and polyurethanes (vinyl chloride). Contrarily, thermosets are polymers which individual chains are covalently bonded during polymerisation. These crosslinked networks are resilient to solvent, creep, and heat softening; therefore, it cannot be thermally recycled. Thermosets are commonly used in the manufacture of glass-reinforced composites such as fibreglass, which employ unsaturated polyesters, epoxy, and phenol-formaldehyde resins. However, in this study, thermoplastics was used as the matrix material for the production of the natural fibre filled recycled based polymer composites.

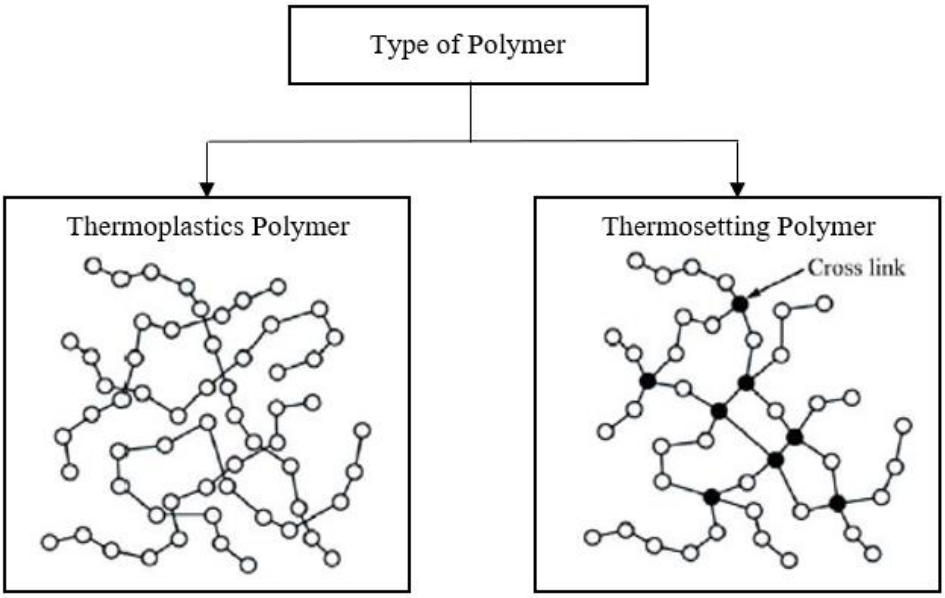


Figure 2.1 Type of Polymer (Liu et al., 2015)

2.3 Thermoplastic

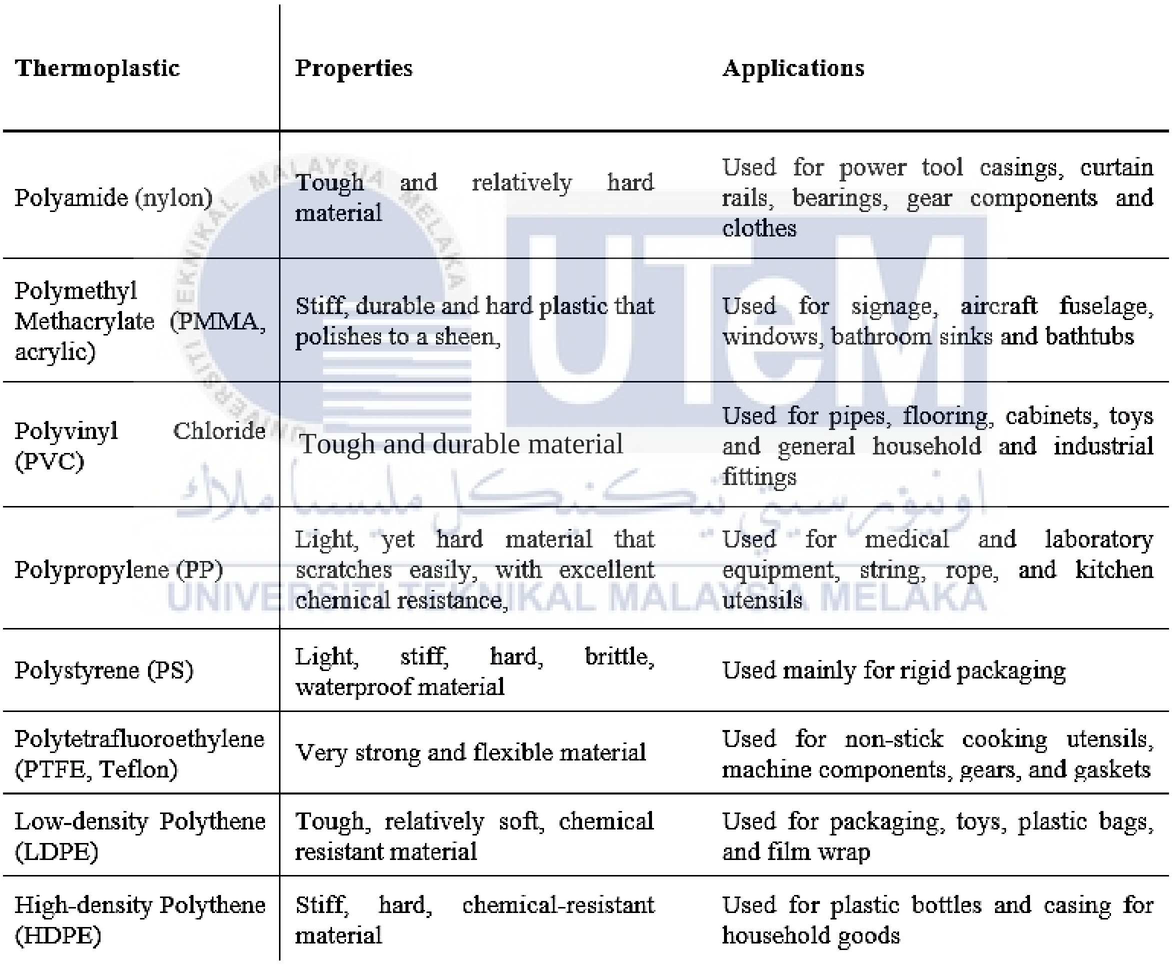
Polymers that are needed to be heated to be processed are known as thermoplastics. Such materials maintained their moulded shape after cooling. Furthermore, these polymers may be reheated and reshaped without significantly altering their characteristics (Taj et al., 2007). Thermoplastics feature one or two dimensional molecular structures with an elevated melting point at higher temperatures. It is also possible to reverse the softening point at high temperatures so that the compound may regain its properties as it cools, making it easier to mould the compounds using normal compression moulding techniques. When it is heated to a temperature greater than melting temperature, these polymers may flow. Plastic deformation occurs as a result of their large molar mass, entanglements, connections, and chain branching, resulting in viscous flow, which was commonly related with rheology (Mitrus & Mościcki, 2011).

As the temperature rises, the thermoplastic begins to soften and flow, either by crystal melting or by passing the glass transition point (Tg). Thermoplastics adopt the form of the mould into which they are put as melt and cool to solidify into the desired shape after processing, commonly by injection-moulding or blow-moulding-like procedures. For thermoplastics, the capacity to reheat, melt, and change form is the most important feature.

Even after it has been formed as a solid, the material may still be processed in this approach. Extrusion, thermoforming, and injection moulding all depend on thermoplastic resin behaviour.

There are few types of thermoplastics including polypropylene, polymethyl methacrylate, polystyrene, polyvinyl chloride that are commonly used in industries nowadays. The application of every type of thermoplastic are shown in Table 2.2.

Table 2.2 Types of thermoplastics and their applications (Matmatch, 2020)

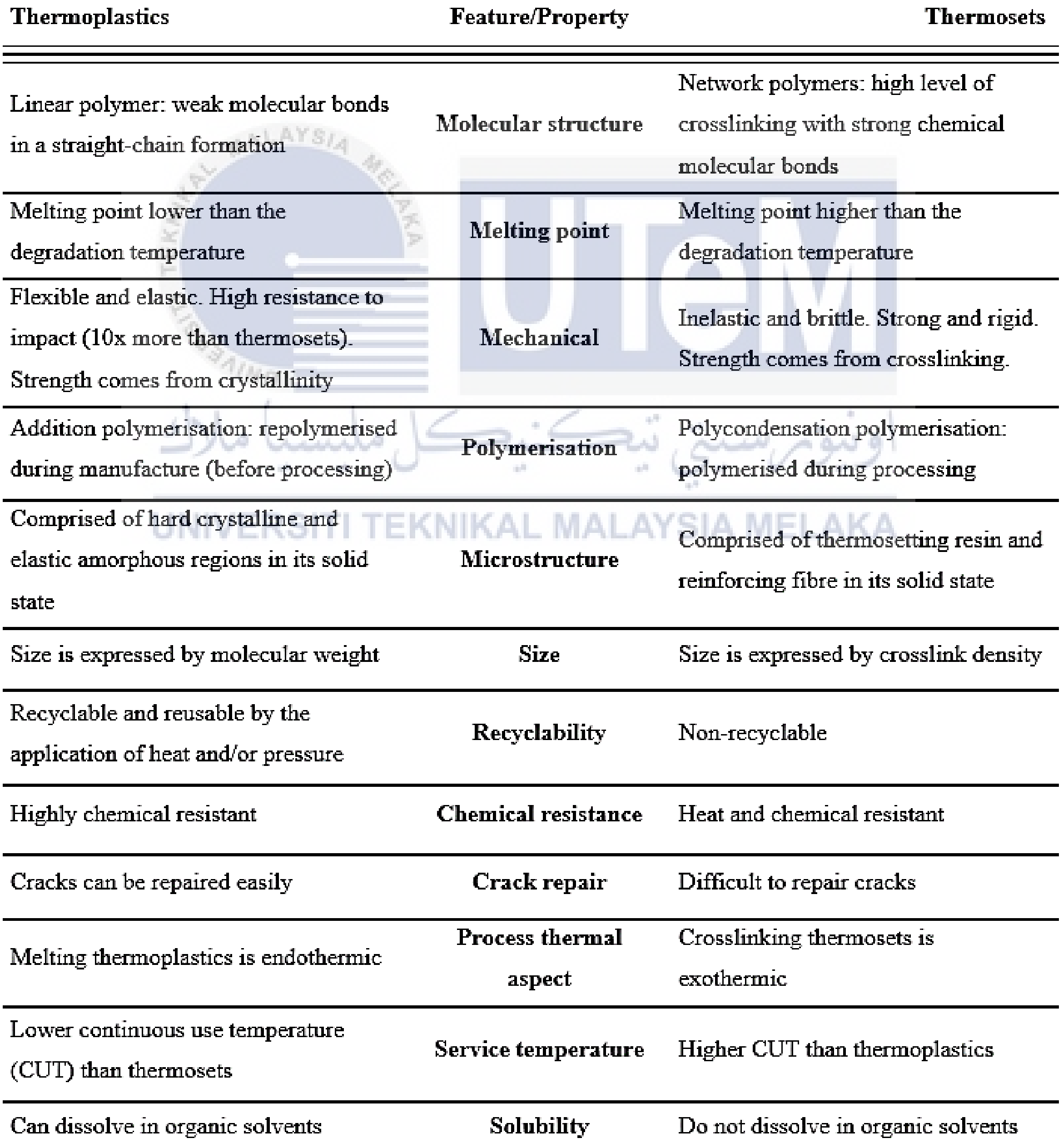


Thermoplastic	**Properties**	**Applications**
Polyamide (nylon)	Tough and relatively hard material	Used for power tool casings, curtain rails, bearings, gear components and clothes
Polymethyl Methacrylate (PMMA, acrylic)	Stiff, durable and hard plastic that polishes to a sheen,	Used for signage, aircraft fuselage, windows, bathroom sinks and bathtubs
Polyvinyl Chloride (PVC)	Tough and durable material	Used for pipes, flooring, cabinets, toys and general household and industrial fittings
Polypropylene (PP)	Light, yet hard material that scratches easily, with excellent chemical resistance,	Used for medical and laboratory equipment, string, rope, and kitchen utensils
Polystyrene (PS)	Light, stiff, hard, brittle, waterproof material	Used mainly for rigid packaging
Polytetrafluoroethylene (PTFE, Teflon)	Very strong and flexible material	Used for non-stick cooking utensils, machine components, gears, and gaskets
Low-density Polythene (LDPE)	Tough, relatively soft, chemical resistant material	Used for packaging, toys, plastic bags, and film wrap
High-density Polythene (HDPE)	Stiff, hard, chemical-resistant material	Used for plastic bottles and casing for household goods

2.3.1 Advantages of Thermoplastic

In terms of material properties, one of the most significant distinctions is that thermoplastics are recyclable, but thermosets are not. thermoplastics may be reused because of their capacity to soften, melt, and resolidify on cooling. Although thermosets can't be recycled since they cross-link and become "set" during processing, they may be reground and used as filler material, which is a sort of recycling. The comparison between thermoplastic and thermoset are shown in Table 2.3 (Christopher C. I, 2011).

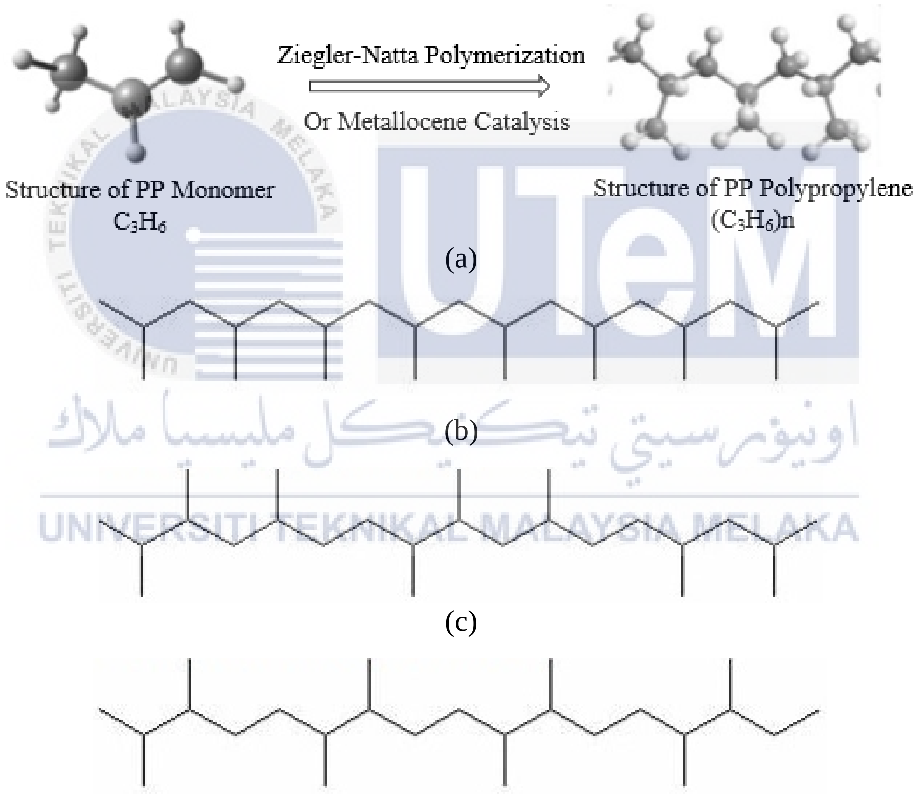
Table 2.3 Thermoplastics vs Thermosets



Thermoplastics	Feature/Property	Thermosets
Linear polymer: weak molecular bonds in a straight-chain formation	**Molecular structure**	Network polymers: high level of crosslinking with strong chemical molecular bonds
Melting point lower than the degradation temperature	**Melting point**	Melting point higher than the degradation temperature
Flexible and elastic. High resistance to impact (10x more than thermosets). Strength comes from crystallinity	**Mechanical**	Inelastic and brittle. Strong and rigid. Strength comes from crosslinking.
Addition polymerisation: repolymerised during manufacture (before processing)	**Polymerisation**	Polycondensation polymerisation: polymerised during processing
Comprised of hard crystalline and elastic amorphous regions in its solid state	**Microstructure**	Comprised of thermosetting resin and reinforcing fibre in its solid state
Size is expressed by molecular weight	**Size**	Size is expressed by crosslink density
Recyclable and reusable by the application of heat and/or pressure	**Recyclability**	Non-recyclable
Highly chemical resistant	**Chemical resistance**	Heat and chemical resistant
Cracks can be repaired easily	**Crack repair**	Difficult to repair cracks
Melting thermoplastics is endothermic	**Process thermal aspect**	Crosslinking thermosets is exothermic
Lower continuous use temperature (CUT) than thermosets	**Service temperature**	Higher CUT than thermoplastics
Can dissolve in organic solvents	**Solubility**	Do not dissolve in organic solvents

2.3.2 Polypropylene

Polypropylene is a thermoplastic derive from "addition polymerisation" that is synthesised by combining propylene monomers with Ziegler-Natta or metallocene catalyst as shown in Figure 2.2(a). Propylene is a monomer that is generated via gasoline refineries. The PP may be synthesised in (b) isotactic, (c) atactic, or (d) syndiotactic as shown in Figure 2.2. Isotactic polypropylene (iPP) is organised methyl groups (CH_3) at only one side of carbon chain while atactic polypropylene (aPP) is methyl groups (CH_3) arranged in irregular positions and syndiotactic polypropylene (sPP) is methyl groups (CH_3) that in alternating arrangement (Omnesux, 2017).



(a)

(b)

(c)

(d)

Figure 2.2 (a) Polymerization process (b) Isotactic Polypropylene, iPP (c) Atactic Polypropylene, aPP (d) Syndiotactic Polypropylene, sPP (Omnesux, 2017)

PP has low specific gravity, hardness, high stiffness, improved chemical and stain resistance, and superior tensile strength due to its high crystalline nature. PP is ideal for industrial applications because of excellent strength-to-weight ratio. Many known solvents are unable to dissolve at normal temperatures. The molecular weight, copolymers used, and manufacturing processes all have a role in the creation of PP (Begum et al., 2019). As seen in Figure 2.3, polypropylene is a vinyl polymer with every carbon atom bonded to a methyl group. However, the qualities of polypropylene are dependent on the manufacturing parameters such as molecular weight, copolymer components, and molecular weight distribution.

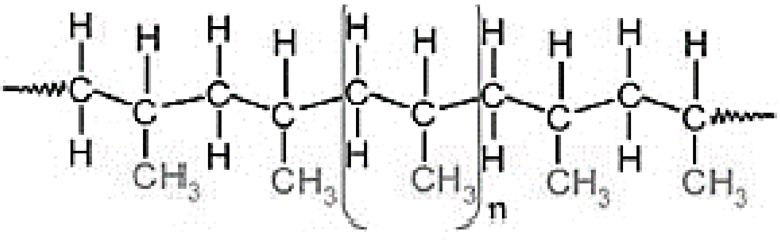


Figure 2.3 Polypropylene Structure (Begum et al., 2019)

Hisham (2016) also mentioned in his studies, PP has higher chemical resistance and is practically impermeable to water. Because of its high specific strength, PP has been used as fibres with remarkable results. However, PP may be dissolved in aromatic and chlorinated hydrocarbons when heated beyond its melting point. It is resistant to a wide variety of substances, including acids, alkaline, and oils, but it is less resistant to oxidation than polyethylene. PP has superior mechanical and dielectric properties, despite its lesser heat and light stability than polyethylene. It is frequently utilised in the automobile sector, with components including as vehicle bumpers, chemical tanks, seat coverings and many more.

There are three factors that make polypropylene the most significant polyolefin. First, polypropylene (PP) is an ideal material for long-term applications due to its low melting temperature, density, and inertness to chemicals. Second, the structural and mechanical qualities of polypropylene may be varied because to the material's high versatility (Wadzani, 2019). Third, different morphological structures of PP can be created by using fillers or reinforcing agents and blending PP with other polymers can result in superior properties (Hisham A. Maddah, 2016).

2.3.2.1 Recycle Polypropylene (r-PP)

Recycled polypropylene (r-PP) is depicted as in Figure 2.4. Since they are simple and inexpensive, recycling is the most prevalent method. This method involves repurposing products in their original form (Singh et al., 2017). Only thermoplastic polymers, which can be remelted and reprocessed into final products, could be used in this process. The polymer is not modified in any way during the mechanical recycling process. Grigore (2017) has justified in this process, the polymer wastes will be chopped, shredded, or washed into the required grade granules, flakes, or pellets, and then extruded to produce the new product by melting. In contrast, recycled material can be mixed with virgin material to obtain a greater characteristic. The amount of polymer waste will be considerably decreased when it is sorted, cleaned, dried, and then directly processed into end goods. The process flow is portrayed the following in Figure 2.5**.** The downsides of this process include diverseness of waste material and the gradual deterioration of product quality over the time due to the recycled resin's low molecular weight. However, despite the fact that this procedure is inexpensive, a significant initial investment is required (Singh et al., 2017).

Figure 2.4 Recycled Polypropylene granulate (Singh et al., 2017)

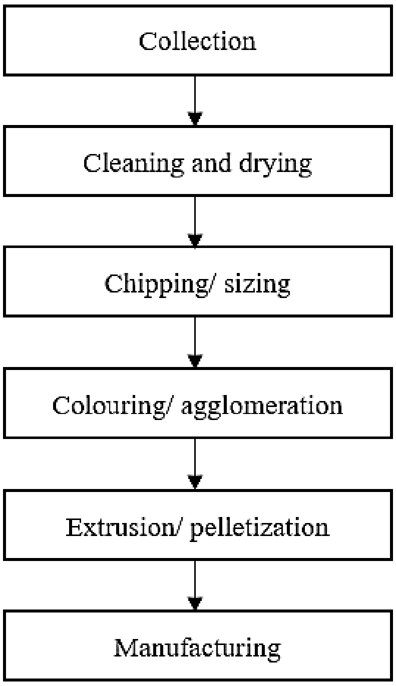


Figure 2.5 Recycling's process flow (Grigore, 2017)

2.4 Composites

Based on book written by Holm Altenbach et al., (2018), “Mechanics of Composite Structural Element”, they refined composite as a composition of two or more different elements or phases. Each element must have an appropriate proportion to be considered, as well as the fact that composite materials are manufactured by mixing their components in various ways. This is important to keep in mind while developing composite materials. The shape of composites and the dispersion of their elements may be used to classify them as shown in Figure 2.6. Based on Figure 2.6, shows that the composites material could be classified into the; (a) laminate with unidirectional or bidirectional layers; (b) irregular reinforcement with long fibres; (c) reinforcement with particles; (d**)** reinforcement with plate strapped particles; (e) random arrangement of continuous fibres; (f) irregular reinforcement with short fibres; (g) spatial reinforcement; and (h) reinforcement with surface tissues as mats, woven fabrics (Altenbach et al., 2018).

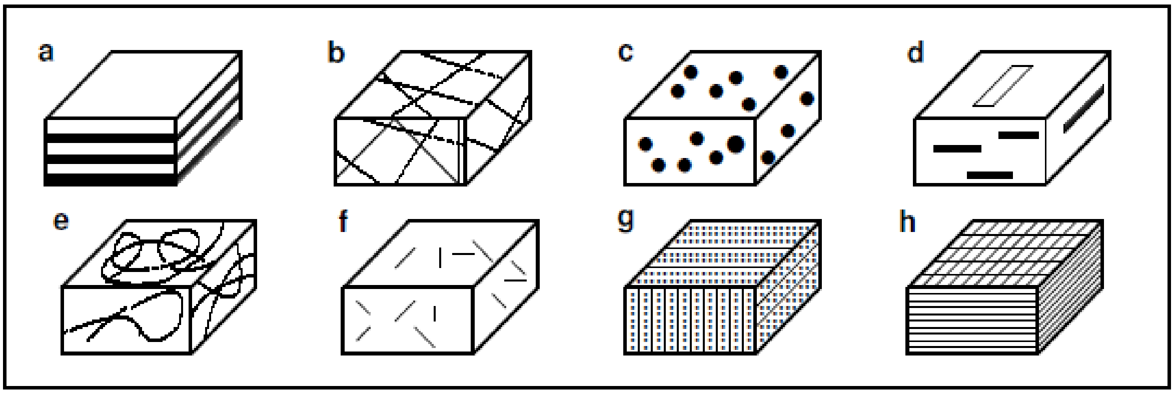


Figure 2.6 Composite materials with different forms of constituents and distributions of the reinforcements (Altenbach et al., 2018).

Due to their numerous benefits likes stiffness and specific strength, composite compounds have drawn significant interest in replacing traditional materials like metals, ceramics, polymers, and wood. Composite materials are becoming more commonly used in our daily lives. Composites have been dubbed as tomorrow's materials as they may provide the features in the future, such as nanocomposites and smart materials (Komal et al., 2019). The matrix and reinforcing elements, as well as the size and form of the components, may all be used to classify composite materials. Composite materials are also versatile materials with mechanical and physical characteristics that are able to be modified to fit a specifically appropriate application and to fulfil its requirements.

According to Harker (2018), composites are materials that have been blended in such a way that we may make better use of their benefits while minimising the impacts of their flaws to some extent. It is a material made up of a matrix and reinforcing material in a multi-phase system. Furthermore, it is constructed of a polymer matrix reinforced with an engineering, man-made, reinforced material, and natural fibre. The loading capacity of composite materials will not be lost in the short run and will not break if there are any faults or cracks in them. In regard to that, Begum et al., (2020) stated that the characteristics of composite materials should be present in terms of microscopic characteristics, it is a non-homogeneous material with a specific interface, where significant distinctiveness are present in the production of component materials, formed materials should have a significant improvement in terms of performance, and the component materials' fraction of volume should be greater than that of the composite materials.

2.4.1 Classification of Composite

Classification of composites are shown in the Figure 2.7. Composites are divided into two parts in the composition which are the matrix and reinforced filler. For the matrix, it was separated into three different matrix which is polymer matrix composites (PMC), ceramics matrix composites (CMC), and metal matrix composite (MMC). In PMC, it was then separated into two more matrix types which are the thermoplastic based and thermosetting based. Depending to the material, the reinforcement might be fibrous, structural or particle. The fibres are either discontinuous which contained short fibres or continuous with typically long fibres. Long fibres are normally organised in spatial, unidirectional, or bidirectional patterns, however irregular reinforcements with long fibres are also achievable. The mechanical characteristics of composites are determined by the orientation and arrangement of short or long fibres. While for short fibres, usually the fibre will be arranged in organised or random oriented (Komal et al., 2019).

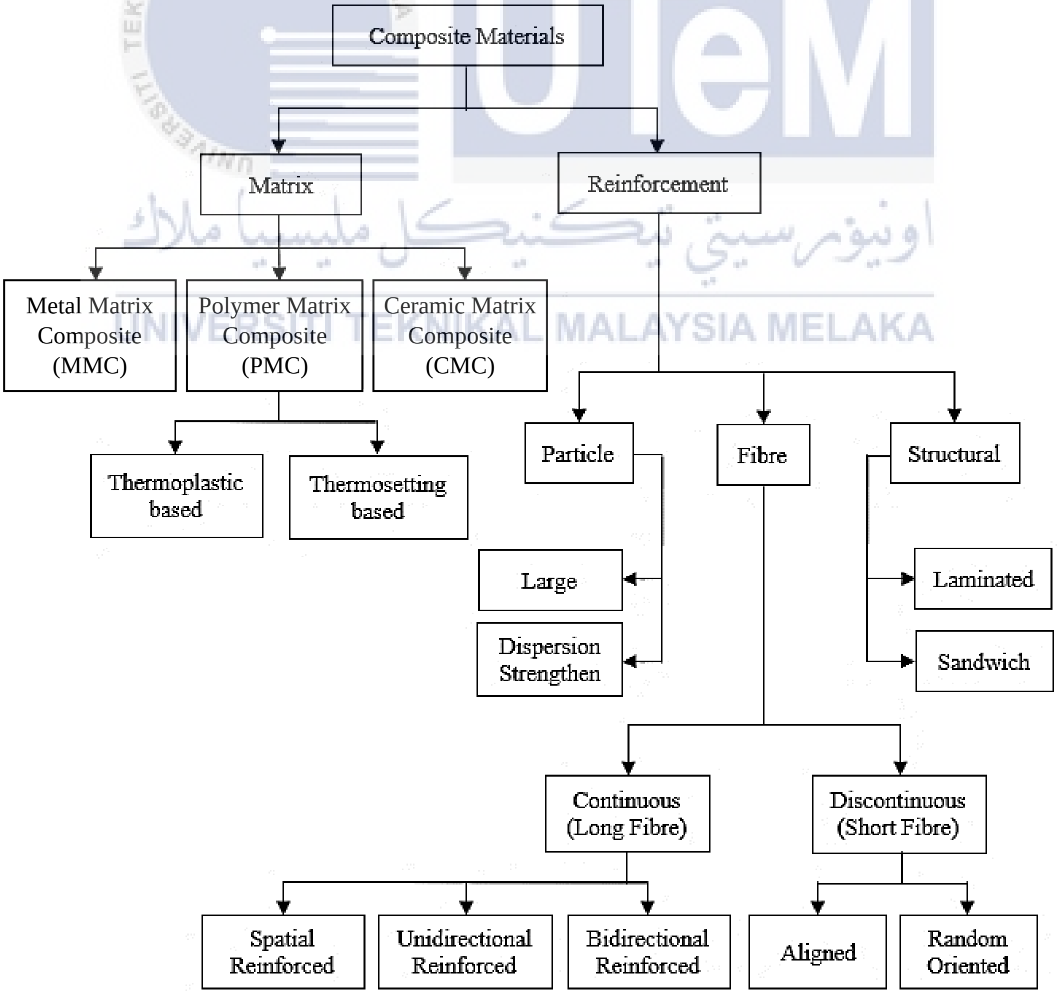


Figure 2.7 Classification of Reinforced Composites (Komal et al., 2019)

2.4.2 Polymer Matrix Composites (PMC)

Polymer matrix composites (PMC) have been gaining popularity practically worldwide due to their low cost and easy production process because it employs organic polymer as the matrix and fibre as the reinforcement. The loading bearing members principle was used by PMC, with the matrix acting as binding and retaining agent to the reinforcement into a solid. The fibres of PMC make it the primary load-bearing component. Furthermore, the increased environmental impact of synthetic fibre based polymer composites' manufacture, disposal, and recycling has prompted the creation of eco-friendly composites, making PMC the best and most prevalent answer for environmental concerns (Begum et al., 2020; Wang et al., 2011).

PMC is now a vital part of a process that is commonly employed in industrial production. It was due to its ease of processing, lightweight nature, increased production, and lower cost. To accommodate the high strength modulus, PMC is currently modified with fillers and fibres. The natural fibre is one of the fibres used in PMC, and it was derived from a variety of plant and animal sources. Currently, the majority of research and product development efforts are focused on the utilisation of plant-based natural fibres as a reinforcing component in polymer composites. Natural fibre-reinforced polymer matrix composites have the potential to be less costly, more durable, and more ecologically friendly than conventional polymer matrix composites; nevertheless, their potential for use in polymer composites has not yet been fully explored (Yashas Gowda et al., 2018).

PMC can be categorized into few categories of matrix and filler system. Single matrix with single filler system is the most common system that been manufactured over the centuries as previous studies done by various researchers. While for hybrid system composite, the matrix and filler also has been hybridized for various applications. According to Albert Seldon and Abilash (2019), when compared to single or individual reinforced polymer composites, hybrid matrix composites with combination of two or more types of polymers in a polymeric composite yield improved stiffness and strength. As a result, crossbreed fusions will unquestionably supply increased arduousness, enhanced advantage and strength, improved impression along with fatigue resistance, breakage durability, and can undoubtedly reduce weight and cost

For hybrid filler composites, each natural fibres have distinct mechanical properties, and their composites react to applied stresses differently. Hybrid fibre systems combining two or more fibres have been studied in order to achieve a synergy of fibre properties. The composites created from such combinations would therefore reflect this synergy. Some fibres have good modulus of elasticity but poor tensile properties, thus they are blended with fibres with higher tensile strength to create a hybrid fibre system that has both the desired properties. Reinforced composites produced from such a system would have improved mechanical properties, allowing for better structural applications (Pai & Jagtap, 2015).

2.4.3 Characteristic of PMC

PMC has its own set of characteristics. In fibre based polymer composites, one of its properties is that it acts as a glue, binding the high stiffness, high strength fibres together firmly and stably. Because it is lightweight and strong, and it offers a wide range of design options, it is also simple to make and mould in any shape or sizes. According to Balakrishnan et al., the low density, high stiffness, and strength of raw materials were necessary for PMC to achieve the desired performance (Balakrishnan et al., 2016). PMC's expansion coefficient is typically substantially higher than fibres. PMCs are made up of a range of organic polymers with short or continuous fibres and various reinforcing agents, allowing them to improve qualities, including fracture toughness, high strength, and stiffness (Wisnom et al., 2006). The PMC is built in such manner that the fibres are able to withstand the mechanical stresses that are applied to them. What the matrix does is to keep the fibres together, allowing load to be transmitted between them as efficient as possible. A polymer matrix reinforced with natural fibres has greater resilience than a conventional polymer matrix. Because of the interfacial link that exists between them, their mechanical and chemical identities are preserved (Netravali & Chabba, 2003).

The fibres are the primary components of the charge carrier ensemble, and the matrix is responsible for keeping them in place. When the fibres are positioned correctly, it transfers energy between them and protects them from environmental harm. In comparison to CMC and MMC, PMC production is less complicated and more accessible due to the ease of manufacturing. When it comes to PMC, one of the most significant disadvantages is that they are nonbiodegradable. However, this may be reduced to some extent by mixing polymers with natural fibres to form the composite materials (Chung, 2017).

The strength and modulus of fibre are much greater than those of the matrix material that is usually used in the preparation of a polymer matrix composite. As a result, fibres take on the role as main load-bearing component. However, in order for fibres to be securely connected, a matrix material with excellent adhesive properties is required. Aspects of polymer matrix composite materials that are particularly noteworthy are higher specific modulus and specific strength that they possess. The specific modulus is defined as the ratio of modulus to density, and the specific strength is defined as the ratio of strength to density. Fibres with high performance and low density are used to reinforce composite materials, resulting in composite materials having high specific strength and specific modulus.

2.4.4 Advantage and Disadvantages of PMC

Oladele et al., (2020) stated that PMC excels in processing matrix, fibres, and other raw materials that are chosen to meet the product condition and performance requirements. The material may be designed using the moulding process, which allows it to be tailored to any shape, size, and quantity. By reducing the number of assembly pieces, integrated moulding can save time, material, and weight. Thus, there are advantages and disadvantage of PMC as shown in the Table 2.4.

Table 2.4 Advantages and Disadvantages of PMC (Oladele et al., 2020)

Advantages	Disadvantages
Low modulus	Automation and mechanisation processes have a modest degree of automation and mechanisation
High density	Poor consistency of the material properties
Lower specific modulus	Poor stability of product quality
Higher melting point, and vaporisation heat with good friction properties and chemical corrosion resistance	Poor long term high temperature resistance
It has a strong temperature resistance in short term and a good ablation resistance	Poor ageing resistance

2.4.5 Application of PMC

Nowadays, PMC is extensively used in the manufacturing sector. PMC has been used in a variety of situations and applications throughout the world. As a consequence, the PMC has gained popularity in high-strength, high-modulus applications such as aerospace, automotive, sports goods, and other high-modulus applications. Furthermore, as a result of extensive study conducted in the area of carbon fibre technology in most recent years, the cost of carbon fibre has been steadily decreasing, allowing it to be used in a wider range of building applications (Das et al., 2019).

Aside from that, to replace traditional metal alloys, the industry is concentrating on the use of polymer composites, thermosets, or temperature-resistant and high-strength thermoplastics, among other materials. Note that this is not only a trend in the automotive industry, but rather a need (Koniuszewska & Kaczmar, 2016). Tires, different belts and hoses, and automobile bodywork are mostly examples of PMC applications in the automotive sector. Bugatti, for example, uses PMC as the primary building material for the car's body

PMC is also developed in aerospace vehicles to store aircraft tires and interiors. PMC is used in auto parts, for example, as a building material for high-performance sports gear. Composite material developments have significantly impacted the evolution of new ships designed for the maritime industry. The lightweight of marine constructions is critical for reducing fuel consumption and mobility, while polymer-based composite materials offer essential water and corrosion resistance properties (Oladele et al., 2020). In earlier years, PMC materials was often employed in the automotive, marine, aerospace, and military sectors. Composite materials are examples of a material in which the final characteristics may be altered by altering the components. This helps create composite materials that are stronger, lighter, and less expensive for applications, including aircraft, automobiles, roofing structures, and interiors (Grigore, 2017).

PMC has shown to be an effective reinforcement in polymer matrices and is possibly user-friendly. PMC also has exceptional corrosion resistance, excellent formability, and mechanical vibration-damping properties. The comparatively high specific strength of PMC allows for weight reduction in final elements of automobile structures in the automotive sector. Similar trend may be used for an aircraft industry. Materials with better mechanical characteristics, such as those required in the construction of military land vehicles, warships, aircraft, and military troops' gear such as bulletproof vests, are in high demand in the military sector (Koniuszewska & Kaczmar, 2016).

2.5 Thermoplastic Composites

Thermoplastic composites may be classified into three types, as shown in Figure 2.8. When compared to synthetic-fibre based thermoplastic composites, natural-fibre reinforced thermoplastic composites have poorer durability, better moisture absorption and lower impact strength. Following that, synthetic fibres are often utilised in structural applications due to their better material characteristics when compared than traditional steel and aluminium. When it comes to mechanical properties, hybrid composites are defined as those that depart either favourably or negatively from the behaviour of a rule of mixtures. The impact can be either negative or positive depends on the design of the layers, the loading patterns, and their relative volume percentages of two kinds of fibres (Jogur et al., 2018).

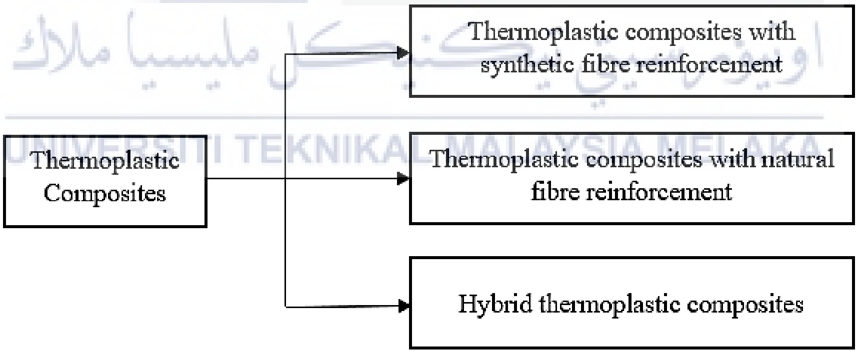


Figure 2.8 Classification of Thermoplastic composites (Jogur et al., 2018)

Incorporating natural fibre into a composite reinforcing system is not a new idea. It was first employed approximately a century ago, mostly in wood items with basic and relatively low-cost components, and it was still in use nowadays (Kandola et al., 2018). Furthermore, Gironès (2012) had stated that the natural fibres generated from plants several advantages over glass fibres, including minimum density, low abrasive wear, abundance availability, renewable and biodegradable nature, cost-effective manufacturing, and recyclability. Several drawbacks include poor compatibility with hydrophobic polymer matrices, poorer tensile strength than glass fibres, heat sensitivity at compounding process temperatures, moisture absorption, and flammability, among other things.

It is becoming more common for industry to utilize the natural fibre for thermoplastic composite, especially in the automotive and aerospace industries. In many industrial applications where, great structural performance is not required, high-strength steel is a viable option that is becoming popular. A significant demand exists in the industrial sector for sustainable development materials such as natural fibres, especially plant fibres. This is primarily due to the many advantages that natural fibres provide in terms of mechanical, economic, and environmental performance (Chegdani & Mansori, 2018).

2.6 Reinforced Filler

In this part, the information pertaining about the filler part for the polymer composites has been reviewed which includes natural fibre, type of natural fibre, properties, and characteristic of natural fibre and in details review has been emphasizes specifically for the KF natural fibres.

2.6.1 Natural Fibre (NF)

Natural fibres were originated from a variety of plants and animals. Cotton, kenaf, flax, oil palm and jute are several examples of cellulose-based natural fibres that were extracted from plants. Mohair, wool and silk are examples of protein-based animal fibres (Yashas Gowda et al., 2018). Previous study made by Deborah and Chung (2017) and AlMaadeed et al., (2012) has mentioned that one of the focus areas has been emphasized to the use for plant-based natural fibres as reinforcement agents in polymer composites applications. Natural fibre reinforced polymer matrix composites may be less expensive, stronger, and more sustainable. However, the potential of such fibres for polymer composites has not been fully explored. Shravan and Allamraju (2019) had stated that with the rise in environmental concerns and awareness about the use of eco-friendly materials, natural fibre composite materials have become increasingly popular. They also mentioned that the advantages of natural fibre composite over the epoxy resin polymer, carbon fibre are low cost and biodegradable. Furthermore, natural fibre are extensively used in aerospace (Asim et al., 2018), automotive (Begum et al., 2019; Pilipović et al., 2020), construction (Navaneethakrishnan et al., 2020), sports (Zhan et al., 2021), and food packaging industries (Preda et al., 2019) .

Nature fibres are categorised into three main type which are animals, minerals and plants as presented in Figure 2.9 (Zhan et al., 2021). The cellulose fibres produced from the plants can be classified into few types such as bast fibres (kenaf, hemp, jute, flax, and ramie), seed fibres (cotton, kapok, and linseed), wood fibres (hardwood and softwood), fruit fibres (coir, oil palm, husk, and luffa), leaf fibres (pineapple, banana, and sisal) and grass fibres (wheat, rice and bamboo). The use of natural fibres is largely dependent to their intrinsic structure and mechanical qualities, which are modified by their habitat, climatic conditions, harvesting period, and extraction process (Kabir et al., 2012). For this study, we are focusing natural fibre plant-based which are kenaf fibre (KF).

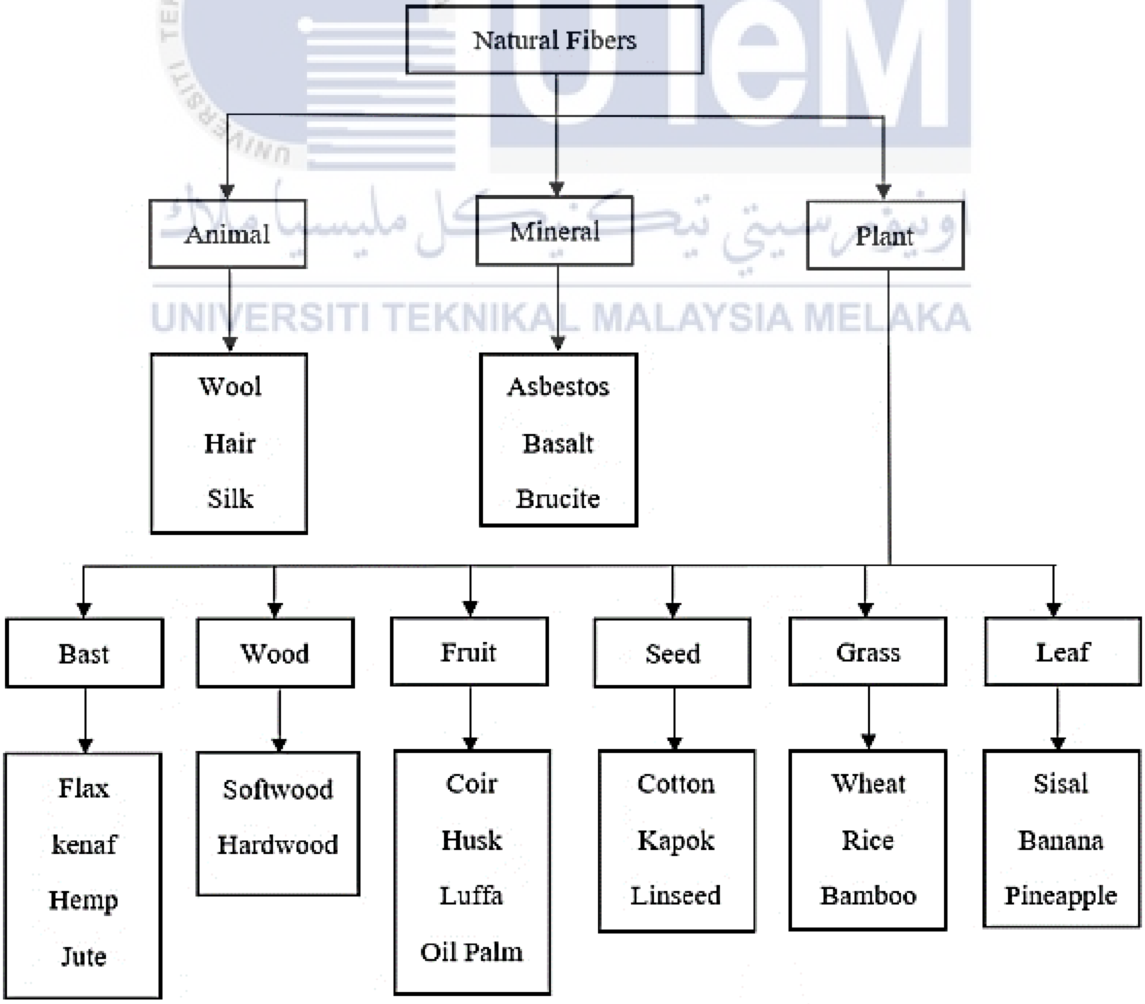


Figure 2.9 Classification of fibres (Zhan et al., 2021)

Example of natural fibre are shown in Figure 2.10 which are commonly used to reinforced polymer and has acted as a filler for polymer composites. The entire fibres are obtained from plant source which going through the extraction process.

Figure 2.10 Example of Plant Fibres (Arifur Rahman et al., 2015)

2.6.2 Structure of NF

Plant fibres feature complex cell structures that are made up of composite cells. The cellulose microfibrils in fibres enhance the hemicellulose and lignin matrix. The cellulose microfibrils are helically wounded alongside the hollow fibre axis, as seen in Figure 2.11 (John & Thomas, 2008). The helical arranged shape integrates the fibre strength since it takes a lot of energy to uncoil the orientated fibrils (Dicker et al., 2014). While, hemicellulose is essential for moisture absorption, biodegradation, and heat destruction of the fibre. Furthermore, lignin is the cause of UV damage. For various fibres, the percentage content of each of these components varies. The fibres are typically comprised of up to 20% moisture, 5–20% lignin, and 60–80% cellulose (Arifur Rahman et al., 2015).

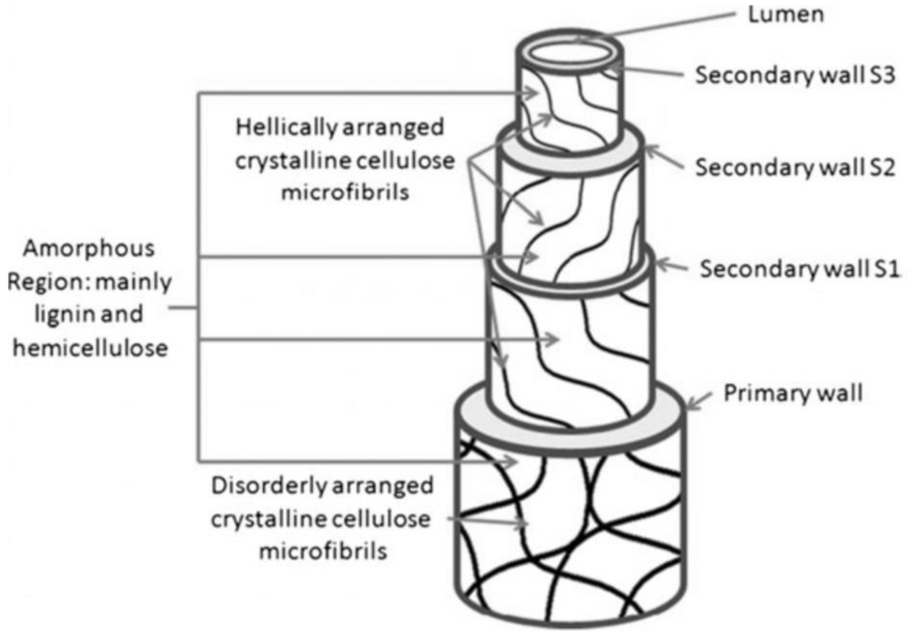


Figure 2.11 Structural composition and arrangement of a natural plant fibre cell (John & Thomas, 2008)

2.6.3 Properties of NF

In comparison to the most extensively used reinforcing glass and other man-made fibres, the mechanical capabilities of natural fibres are much less impressive. The data clearly shown in Table 2.5. Natural fibres particular characteristics (property-to-density ratio), strength, and stiffness, on the other hand, are equivalent to those of man-made fibres due to their lower density (Wambua et al., 2003). The extraction source has an impact to the mechanical characteristics of fibres. The bast fibre produced from the outer fibrous bark has higher flexural strength and modulus of elasticity than the leaf based fibres. The cellulose content and microfibrillar angle are the primary determinants of mechanical characteristics in natural fibres. The young's modulus of natural fibre falls as the diameter increases. A fibre with higher cellulose percentage and a lower microfibril angle is ideal for use as reinforcement in polymer composites (Arifur Rahman et al., 2015). The degree of polymerisation of cellulose in natural fibre has a considerable impact to the mechanical qualities. The mechanical properties of natural fibres and man-made fibres are shown in Table 2.5 (Mohammed et al., 2015; Taj et al., 2007).

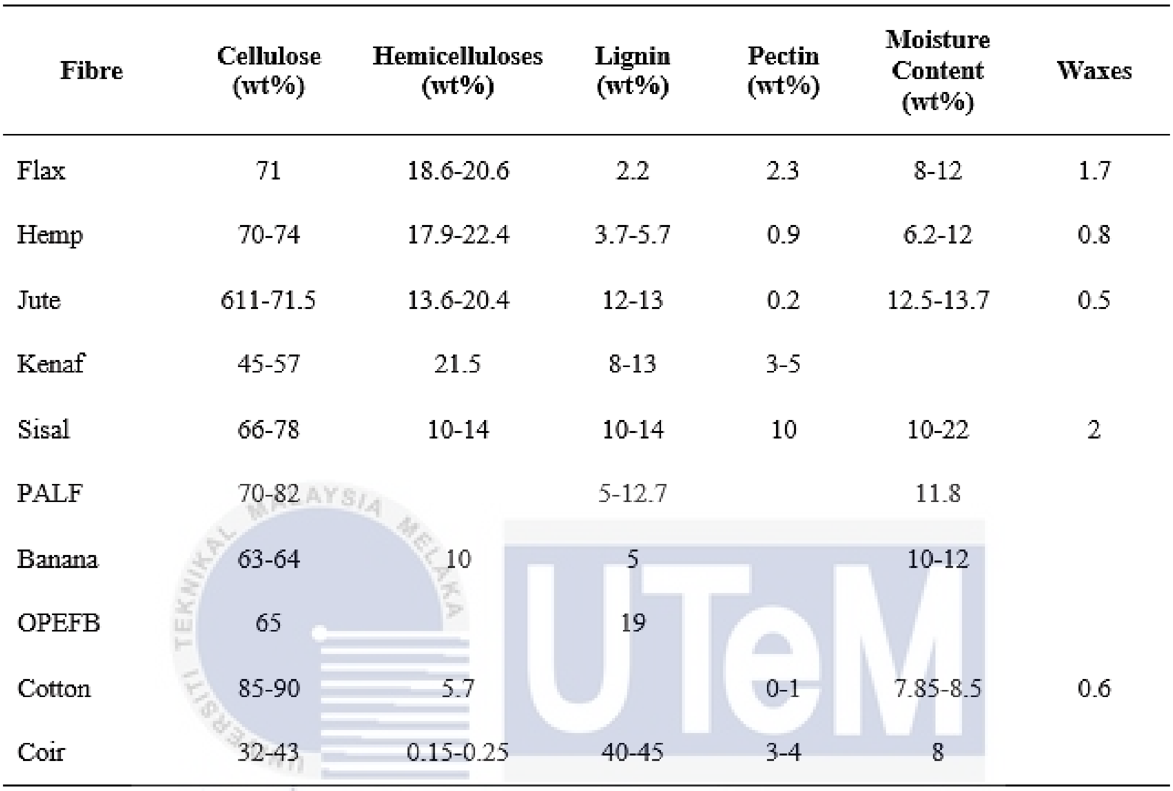
Table 2.5 Mechanical properties of natural and man-made fibres (Mohammed et al., 2015; Taj et al., 2007)

Fibre	Density (g/m^3)	Elongation (%)	Tensile strength (MPa)	Young modulus
Natural Fibre				
Jute	1.3	1.5 - 1.8	393 - 773	55
Sisal	1.5	2 - 2.5	510 - 635	9.4 - 28
Flax	1.5	2.7 - 3.2	344	27
Kenaf		1.5	389 - 930	35 - 53
Pineapple	1.5	2.4	170	62
Cotton	1.5 - 1.6	7 - 8	287 - 597	5.5 - 12.6
Hemp		1.6	690	
Coir	1.2	30	175	4 - 6
Ramie		3.6 – 3.8	400 - 938	61.4 - 128
Wool		25 - 35	120 - 174	2.3 - 3.4
Spider Silk		17 - 18	875 - 972	11 - 13
OPEFB	0.7-1.55	248	3.2	2.5
Man-made Fibre				
E-glass	2.5	2.5	2,000 - 3,500	70
Aramid	1.4	3.3 - 3.7	3,000 - 3,150	63 - 67
Carbon	1.4	1.4 - 1.8	4,000	230 - 240

2.6.4 Chemical Composition of NF

Natural fibres have different chemical compositions based on the type of fibres. Table 2.6 shows the plant fibres' chemical composition, as well as their structure. Plant fibres are naturally designed composite material. Cellulosic microfibrils are reinforced with amorphous lignin and/or with hemicellulose matrix in the fibre structure. Except for cotton, most plant fibres are made up of cellulose, hemicellulose, lignin, waxes, and few water-soluble chemicals, with cellulose, hemicelluloses, and lignin being the most common elements (Taj et al., 2007). Fibre qualities are influenced by the properties of its components. Due to its low resistance, hemicellulose is responsible for the fibre’s biodegradation, micro absorption, and thermal degradation, while lignin is thermally stable but vulnerable to UV damage. Various fibres have different percentages of each of these components. In general, the fibres are comprised of 60-80% cellulose, 5-20% lignin, and up to 20% moisture. The fibres' cell wall undergoes pyrolysis and leads to the development of char at higher processing temperatures. The lignocellulose is protected from further heat deterioration by these charred layers.

Table 2.6 Chemical composition of natural fibre (Taj et al., 2007)



Fibre	Cellulose (wt%)	Hemicelluloses (wt%)	Lignin (wt%)	Pectin (wt%)	Moisture Content (wt%)	Waxes
Flax	71	18.6-20.6	2.2	2.3	8-12	1.7
Hemp	70-74	17.9-22.4	3.7-5.7	0.9	6.2-12	0.8
Jute	611-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5
Kenaf	45-57	21.5	8-13	3-5		
Sisal	66-78	10-14	10-14	10	10-22	2
PALF	70-82		5-12.7		11.8	
Banana	63-64	10	5		10-12	
OPEFB	65		19			
Cotton	85-90	5.7		0-1	7.85-8.5	0.6
Coir	32-43	0.15-0.25	40-45	3-4	8	

The β-d glucopyranose units of cellulose, a non-branched macromolecule, come in a variety of lengths (Mohd et al., 2014). Three elements that form cellulose are of C, H, and O_2. Figure 2.12(a) depicts an example of cellulose chemistry for KF. The $C_6H_{10}O_5$ is the general chemical formula for cellulose. The greater the cellulose concentration, the higher the fibre’s modulus and, therefore, affecting its strength (Akil et al., 2011). The hydrophilic hemicellulose is found available in the main cell wall. It was utilised to reinforce the cell membrane. Figure 2.12(b) depicts an example of hemicellulose's chemical structure in the fibre. Furthermore, the chemical structure of lignin is shown in Figure 2.12(c). Lignin was served for two which are to provide the mechanical support and strength for the plant. Between the lignin and the cellulose, the two components of cell wall are held together by the lignin. Lignin is also involved in the regulation of UV degradation in fibre (Akil et al., 2011). Pectin is one of the cell wall components that contributes to the plant's flexibility and water solubility. Pectin surrounds and keeps cellulose and hemicellulose together on the stem. Because of this, pectin is removed from the stem in order to separate the stem's hemicellulose and cellulose (Thakur et al., 2013).

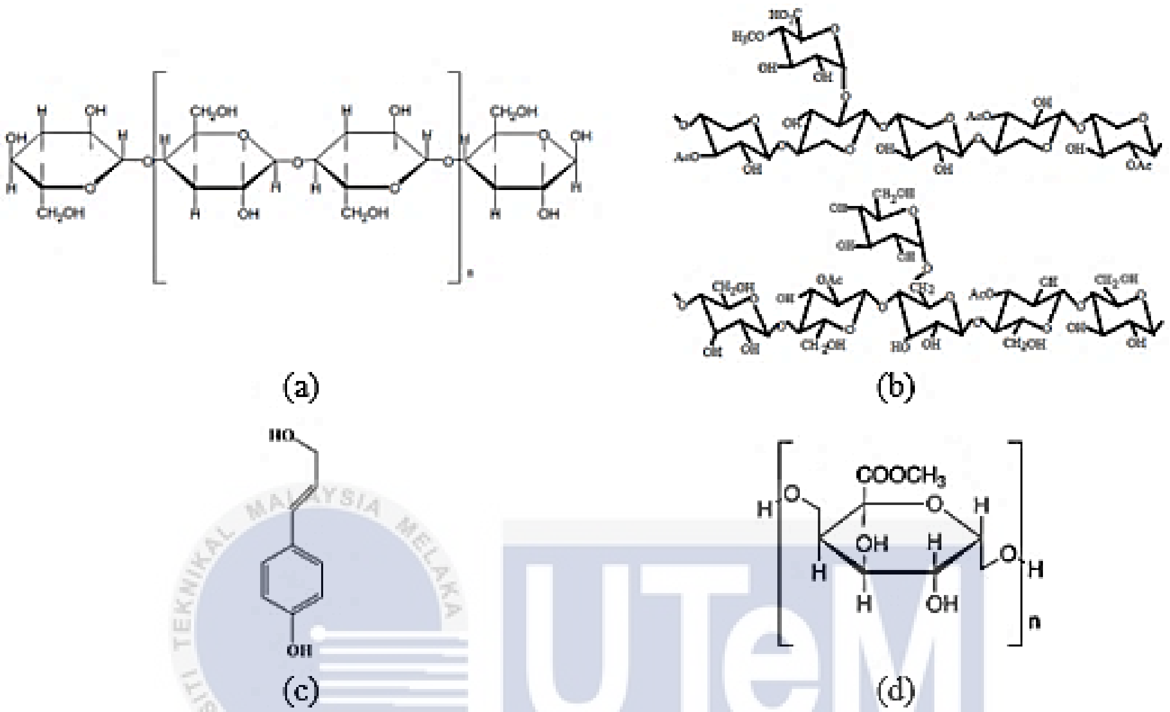


Figure 2.12 Chemical structure of (a) cellulose; (b) hemicellulose; (c) lignin; (d) pectin (Akil et al., 2011; Thakur et al., 2013)

2.6.5 Advantages and Disadvantages of NF

Natural fibres (NF) have already attracted the attention of researchers as reinforcing material due to their benefits over other well-established materials. They are eco-friendly, entirely biodegradable, widely accessible, renewable, and inexpensive, with a lower density. In comparison to glass, carbon, and aramid fibres, plant fibres are lighter. Plant fibres' biodegradability contributes to healthier ecology, while their cheap cost and good performance meet industrial economic needs (Taj et al., 2007). As a result of the decreased abrasiveness of fibre, composite materials may be processed more efficiently and recycled more easily. Natural fibre-reinforced plastics are the most ecologically beneficial materials that may be composed at the end of their life cycle since they use biodegradable polymers as matrix.

There are various limitations to the use of natural fibres in composites, such as poor wettability, incompatibility with certain polymeric matrices, and excessive moisture absorption that limit their use. The mechanical characteristics of composite materials are generated from untreated plant fibres which are often inadequate. Surface treatment or curing agents may be necessary before composite production is executed in several circumstances in order to overcome these drawbacks.

2.7 Kenaf Fibre (KF)

Kenaf or Hibiscus Cannabinus L., is an economically viable and environmentally friendly alternative fibre crop. Recently, Chu (2021) had stated that the KF also a fast-growing dicotyledonous fibre plant from the Malvaceae family native to India and Africa. Kenaf stems are normally round and have thorns that range in size from tiny to large, depending on their species. Kenaf is composed of two kinds of fibres: long fibres found in the cortical layer and short fibres found in the ligneous zone. Kenaf primary fibres are polygonal and short, measuring between 1.50 and 6.00 mm. They have a striated and uneven appearance on the surface. The lumen's thickness fluctuates widely across the cell, occasionally disappearing completely (Herrera Franco & Valadez-González, 2005).

According to Giwa Ibrahim (2019), kenaf is composed of multiple usage components such as stalks, leaves and seed. The researchers also mentioned that within each of these plant components there are various useable portions which are fibres and fibres stand, proteins, oils, and allopathic chemicals. Besides, they found that many factors had influenced the yield and composition of kenaf plant components, including cultivar, planting date, photosensivity, length of growing season, plant populations, and plant maturity. Therefore, it is necessary to understand the production factors that influence these plant components and their composition. Another study by Ryu (2017), highlights that kenaf is a valuable medicinal crop which originated was from Africa.

In this study, the researchers observed that kenaf plant contained various functional compounds. Some researcher found that each of kenaf component have their own purposes as shown in Table 2.7.

Table 2.7 Use of kenaf component

References	Kenaf components	Findings
Ryu et al., (2017)	Stem bark	Stem bark can be used for anaemia.
Ryu et al., (2017)	Flower	Juice of the flower can be used for biliousness.
Sim & Nyam, (2019)	Leaves	Traditional medicine uses kenaf leaves to treat blood, bilious, coughs, diabetes, and throat disorders.
Giwa Ibrahim et al., (2019)	Seeds	Dietary fibres, oil, and proteins are all found in the seeds. The oil is being used as a new source of functional edible oil with anticancer and antioxidant properties.

Based on the following Figure 2.13, it shows that the components of kenaf plant where (a) is leaf, (b) is stem bark, (c) is flower and (d) is the seeds. Mahjoub (2014) and Parvej (2020) observed that the kenaf plant can reach a height of more than 3 metres in 3 months, with a stem diameter of 25 to 51 mm, and it takes about 3 months from planting to harvest. In addition, according to Parvej (2020), the yearly yield and growth rate of the kenaf plant are higher as it can grow up to 10 cm per day under optimal conditions. They also mention that the spectrum of weather and geographical condition to grow kenaf, but it requires lower extent of pesticides and fertilisers compare to other plants.

(a) (b) (c) (d)

Figure 2.13 Shows the components of the kenaf plant (a) leaf, (b) stem bark, (c) flower and (d) seeds (Ryu et al., 2017)

KF can be obtained via extraction process. Fibre of kenaf plant can be harvested through the core or bast. As seen in Table 2.8, different parts of kenaf plant contain different percentages of composition. Hemicellulose is responsible for the fibre's biodegradability, thermal decomposition and moisture absorption, whereas cellulose supplies the fibre’s structural integrity (Akil et al., 2011). As a result, choosing the right proportion of kenaf fibre may assist researchers and manufacturers in achieving their desirable characteristics for use in a variety of applications. Rouison (2004), also agree that the proportion of components in kenaf fibre impacts its overall capabilities.

Table 2.8 Composition for KF parts (Akil et al., 2011; Tezara et al., 2016)

Organic composition of KF				Inorganic (ash content) (%)	Fibre length (Average) (mm)	Composition of whole stem (%)
Fractions	Cellulose (%)	Hemicellulose (%)	Pentosan (%)			
Bast	56.4	26.2	13.4	2.2	2.48	34.3
Stem	48.7	28.1	19	1.8		
Core	46.1	29.7	20.7	1.6	0.72	65.7

Kenaf has been used as cordage crops for centuries to manufacture twine, rope and sackcloth, among other products. Kenaf bast fibre is the material of choice for a broad variety of extruded, moulded, and non-woven goods due to its exceptional flexural and tensile strength (Begum et al., 2020). As an alternative to glass fibre, this fibre is currently widely used as a reinforcement material in polymer composite. Kenaf is being utilized in wide range of novel functions, including paper, absorbents, animal feeds, and construction materials. Kenaf has been rated particularly ecologically friendly for two primary reasons, which are it collects a substantial amount of carbon dioxide, and it takes nitrogen and phosphorus from the soil (Zampaloni et al., 2007).

2.8 Surface Modification

This part has explained on the chemical treatment that have previously studied in previous research.

2.8.1 Chemical Treatment

As stated by Tezara (2016), the main reasons that influence the mechanical characteristics of KF as a result to surface modification is chemical treatment of natural fibres. KF tends to react with polymer's hydroxyl group because of hydrophilic nature of fibres. Pectin, Lignin, natural oils coating, and waxy compounds the external surfaces of the fibre cell wall that are chemically removed from natural fibres. Most typically, plant fibres are bleached or cleaned using sodium hydroxide (NaOH). Various treatments are employed to enhance the matrix-fibre bond of NFRC.

In corresponding to this Mwaikambo and Ansell (2002) mentioned that bleaching, acetylation, and alkali treatment are all common treatments for natural fibres. Also, Sgriccia (2008) also mentioned in his studies that silane and alkali treatment are utilised to improve the adhesion between hydrophilic natural fibres and the hydrophobic epoxy matrix. Interfacial connection between fibre and matrix must be strengthened through chemical treatment with coupling agent (Venkateshwaran et al., 2011). By altering the surface of the fibres in bio-composites, moisture absorption and interfacial binding strength with the polymer matrix may be improved (Liu et al., 2015). It has been discovered that hybrid composites absorb less water than non-hybridised composites.

A recent study done by Ibrahim et al., (2018), found out that 6% NaOH show the highest values in terms of tensile strength of the treated kenaf fibres. The KF was soaked in the chemical solution for 3 hours before dried in oven at temperature of 80°C for 6 hours. The findings of the research are tabulated in the following table. It is clearly shown that the strength of KF is at its peak when treated with 6% NaOH solution. However, as the concentration of the NaOH get to 8%, the tensile strength significantly drop due to possibility of the higher solution treatment agent has degraded the fibres and reduce its properties.

Furthermore, concentration of NaOH that were less than 4% show a huge gap in the result of tensile strength compared to the untreated KF. Table 2.9 showed the result of study done by Ibrahim et. al., 2018.

Table 2.9 Tensile properties of treated and untreated kenaf fibre (Ibrahim et. al., 2018)

NaOH (%)	Tensile Strength (MPa)
Untreated	129.10
2	25.28
4	104.32
6	267.69
8	89.58

It has been proven that lignin and hemicellulose extraction, as well as polymerization levels, are directly affected by the alkaline treatment of the cellulosic fibrils (Jähn et al., 2002). Fibre treatment may be as easy as soaking the fibres for a certain period of time in a solution of sodium hydroxide (NaOH). NaOH concentration percentage and treatment time have taken into consideration for the majority of studies on the effects of NaOH on fibre strength.

2.9 Related Testing and Performances of NF based r-PP Composites

The summary from prior research is summarized in Table 2.10. The summaries include the different type of reinforced filler, matrix, treatment and manufacturing method.

Table 2.10 Summary of previous research

Type	Matrix	Treatment				Manufacturing Method	Summary	Ref.
		Chemical	Concentration (%)	Time	Temp (°C)			
Kenaf	PLA	NaOH	5	2h	room	Bed lay-up Compression Moulding	PLA/kenaf composites had significantly higher mechanical and thermo-mechanical properties than the PLA matrix alone.	(Huda et al., 2008)
Flax		NaOH	0, 5, 10, 15, 20	30min	room		As the concentration in chemical fibre processing increases, the fibre bundles' tissue composition changes and their cellulosic fine structure becomes more polymorphic.	(Jähn et al., 2002)
Kenaf	PU	NaOH	2, 4, 6	3h		Compression Moulding	Tensile stress and strain decreased as NaOH concentration increased, while modulus increased slightly.	(El-Shekeil & Sapuan, 2014)
Kenaf	Epoxy	NaOH	6	48h, 144h	room	Vacuum Bagging Technique	The fibre structure deteriorated for 144h treatment while for 48h treatment the impurities are removed from surface	(Fiore et al., 2015)
Kenaf	Epoxy	NaOH	6	48h	25	Hand Layup	The treated fibre composites outperformed the untreated fibre composites, with a 5% improvement over the untreated fibres.	(Mutasher et al., 2011)
Kenaf/Starch	PVA, PEG, Glycerol	NaOH	2	1h	90	Hot Press Moulding	Composites' physical properties are strongly influenced by the degree of interfacial adhesion between kenaf fibre and matrix.	(Song & Kim, 2013)
Jute	Epoxy	NaOH, Silane, NaOH-Silane	1	1h		Vacuum Bagging Technique	The combined alkali and silane treatment managed to improve the properties of the material more than either alkali or silane treatment done separately.	(Dilfi K.F. et al., 2018)

OPEFB		NaOH, KOH, $Al(OH)_3$	15	40min	130		Pre-treatment with NaOH and KOH showed only minor differences across all tests, indicating that either one could be the best alkaline pre-treatment solution for natural fibre.	(Latip et al., 2019)
Kenaf, E-glass	PP	NaOH, NaOH-Silane	1-8	24h	45	Compression Moulding	Tests show that 30% fibre and 6% NaOH are the best concentrations for alkali–silane treatment of kenaf fibres. Throughout all scenarios, the mechanical strength of PP composite reinforced kenaf fibre treated with alkali–silane outperform those of untreated and alkali treated KF.	(Asumani et al., 2012)
Kenaf (Bast, Core)	r-PET, r-PP	NaOH	6	2-4h		Injection Moulding	Tensile testing revealed that the extra fibre loading reduced both elongation at break and tensile strength. In comparison to the kenaf core, the composite filled with kenaf bast fibre has higher toughness, elongation at break, and tensile strength values. As filler loading increases, kenaf core particles tend to agglomerate because of their fibrous structure.	(Marzuki et al., 2019)
Sisal	PP, PLA	NaOH	6			Injection Moulding	The combination of sisal fibres did not affect the tensile strength but increases the composites young's modulus. The composites' marginal changes in tensile characteristics are explained by the fibres' minimal impact on the interfacial contact between the fibres and matrix.	(Ngaowthong et al., 2019)

2.10 Summary

In summary, it is crucial in the engineering of composite materials to accomplish wettability or compatibility between elements of composites (fibre and matrix). Processing techniques, chemical and physical modification methods were reviewed to improve fibre-matrix interfacial bonding and enhance mechanical properties, particularly tensile properties of the composites.

CHAPTER 3

METHODOLOGY

In this chapter, the process flow of the research methodology was clearly described. The principle of the methods used to carry out this research was included in the methodology of this study. Materials preparation, design of experiment, and fabrication methods, as well as related experimental testing, are all discussed. The American Standard for Testing and Materials (ASTM) Standard was closely referred as a guideline in performing the entire experimental testing.

3.1 Overview of Methodology

For this research, it was started with raw material preparation and characterisation followed by fabrication process and testing in order to complete the workflow. Preparation of reinforced filler which was kenaf fibre (KF) has been carried out. The KF was divided into two equal parts of untreated and treated with sodium hydroxide (NaOH) solution. Then, the fibre going through drying process before being grinded into smaller particles. The fibres were sieved into the sizes of 62µm. For the matrix, recycled polypropylene (r-PP) was utilized. Next is the fabrication process, which involving melt blending method using an internal mixture. The raw material was blended by varying the fibre loadings into 10wt%, 20wt%, 30wt% and 40wt% as 0wt% filler content was used as control. As for the matrix, r-PP was used. The sample was then be tested with several mechanical, and physical testing and the results were analysed to come up with the overall findings of this study. All the findings were concluded in this research in accordance with the stated objectives as available in the Chapter 1. Figure 3.1 shows the systematic flow chart of an overview of the experimental methodology.

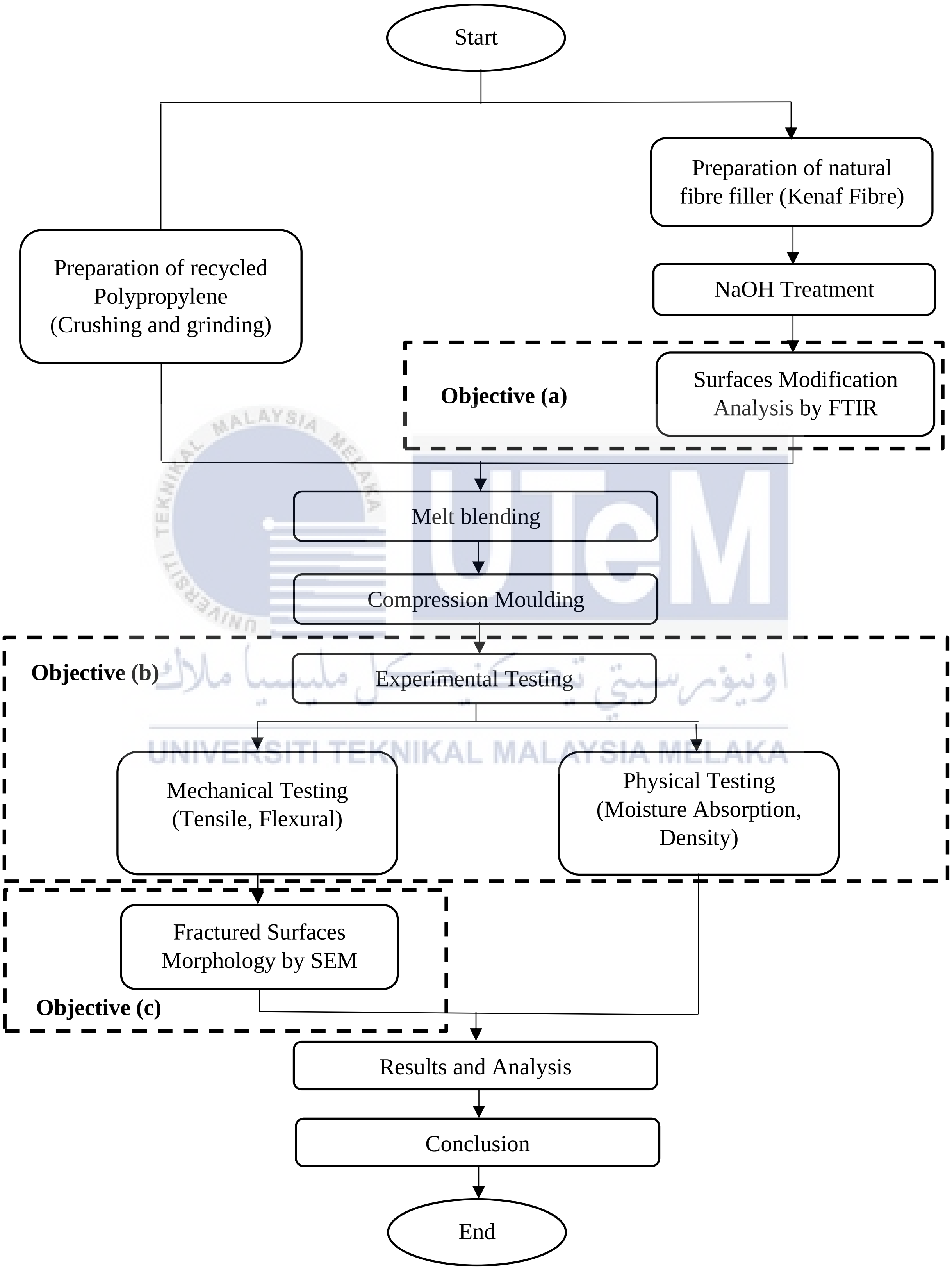


Figure 3.1 Overview of Methodology

3.2 Raw Material Preparation

In this study, for raw materials preparation, it was divided into two main categories which comprising of the preparation for natural fibre (KF) as reinforcing filler and preparation of r-PP polymer as a matrix. The following parts were detailed out the specification and characteristic for each raw material that used in this works. The method of preparation used in this research are basically based on the previous work done by prior researchers and also some of it was invented and applied for this study.

3.2.1 Preparation and Surface Modification of Natural Fibre (KF)

When developing polymer composites, NF convey stability issues in blending the matrix with NF filler. Non-cellulosic content holds cellulosic fibrils together in NF. Extra wax and hemicellulose result in a poor interfacial bonding between the fibres and matrix. Non-cellulosic content also contributes to the hydrophilicity and thermal degradation that takes place during processing. To resolve these issues, pre-processing approaches such as chemical treatment are taken into consideration. All the parameter for the preparation of NF are taken from the previous studies; Akhtar et al., 2016; Dilfi K.F. et al., 2018; El-Shekeil & Sapuan, 2014; Huda et al., 2008.

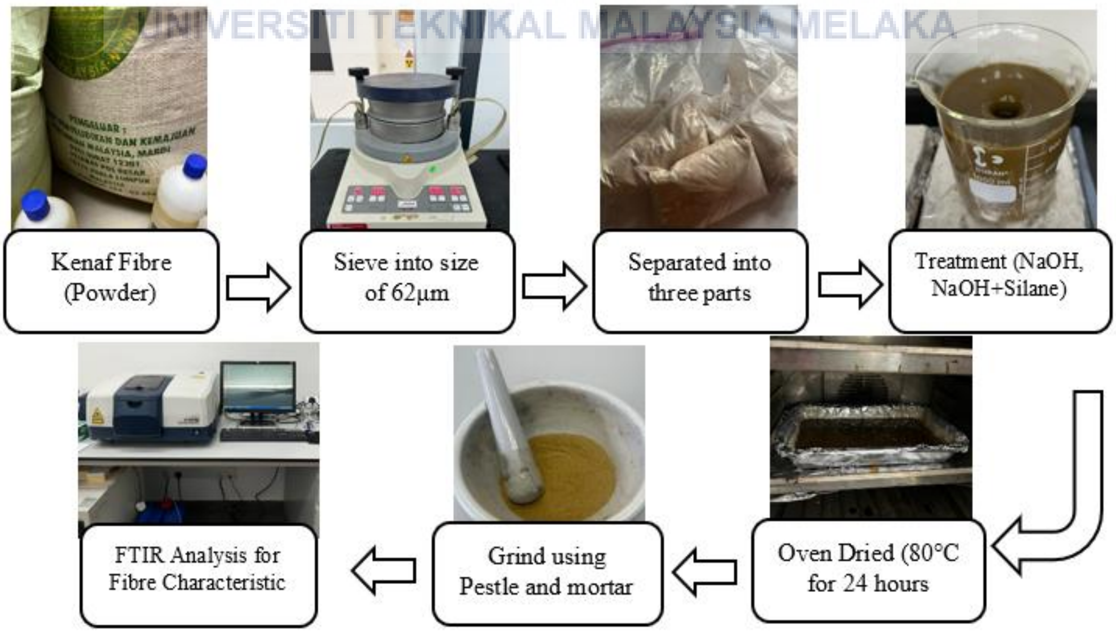


Figure 3.2 Preparation of KF

The preparation of KF powder was conducted in *Composites Lab* at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka). The process flow of the preparation of KF as clearly shown in Figure 3.2**.** KF was supplied by FKM for this study. Firstly, the KF powder was sieved using sieve shaker machine, *Octagon D200 Digital Sieve Shaker* (Figure 3.3) for 20min to separate it into fibre sizes of 62µm.


(a) (b)

Figure 3.3 (a) Sieve Shaker Machine (b) Filtered kenaf powder

For the next step, the fibre powders are treated with chemical treatment, which in these studies are using 10% NaOH solution for 30 minutes. The treatment is shown in Figure 3.4.

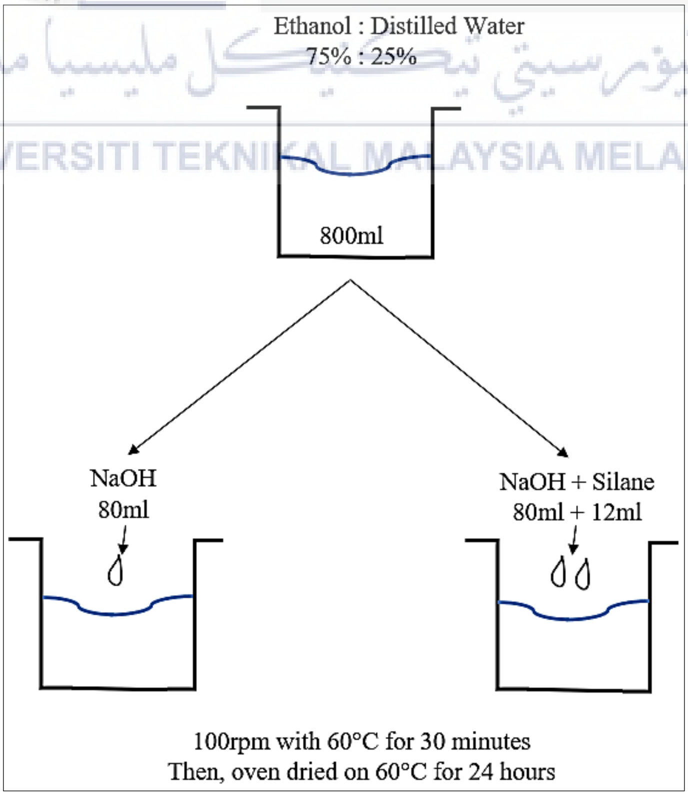


Figure 3.4 Illustration of mixing solution for KF surface treatment

About 40g of filtered kenaf powder shown in Figure 3.5(a), was measured and put in the beaker. The treatment was performed in large batches of 800ml of solution in 1000ml beaker where three part of the solution was ethanol (Figure 3.5(f)), and one part of the solution was distilled water solutions. Then, for the NaOH treatment, 80ml of NaOH solution is added to the premix solution as in Figure 3.5(b)(c). and the solution were heated on the hot plate with the temperature of 60°C and stirred with magnetic bead. Meanwhile, the NaOH + Silane solution were prepared the same way except the 12ml of 3-aminopropyltriethoxysilane (Silane) as in Figure 3.5(d)(e) was added to the solution.

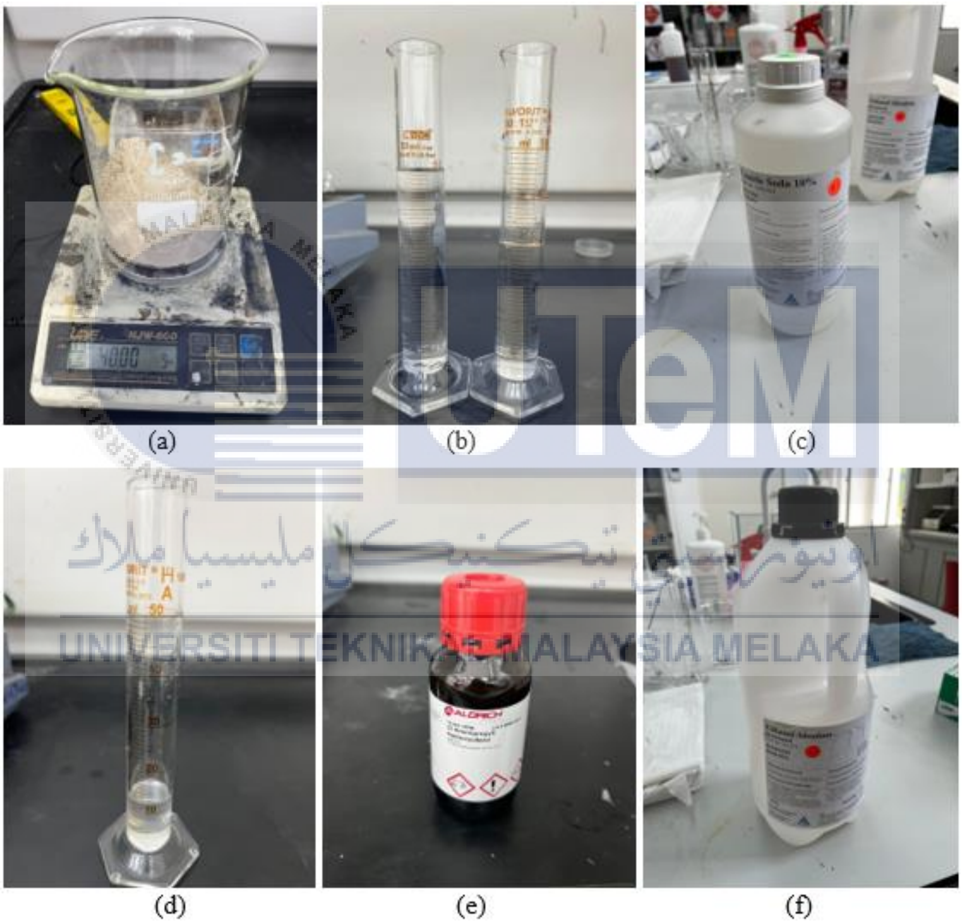

(a) (b) (c)
(d) (e) (f)

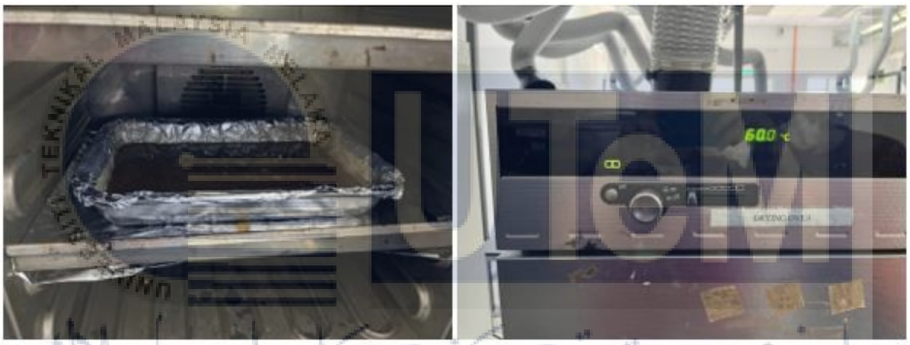
Figure 3.5 (a) kenaf powder (b) 80ml of NaOH solution (c) NaOH solution (d) 12ml of Silane (e) 3-aminopropyltriethoxysilane (Silane) solution (f) 95% Ethanol solution

Afterward, the solution is kept stirring until the solution mixed well for half an hour. Figure 3.6 shown the solution are stirred using magnetic stirrer on top of hot plate. The temperature was maintained at 60°C (Figure 3.6 (b)).


(a) (b)

Figure 3.6 (a) Solution are stirred using magnetic stirrer on top of hot plate (b) temperature maintained at 60°C

After that, the mixed solutions were oven dried with the temperature of 60°C for 24 hours. Figure 3.7 shown the process of the solution were oven dried.



(a) (b)

Figure 3.7 (a) solutions were placed in the oven (b) Oven temperature of 60°C for 24 hours

After done drying, the treated kenaf powder are crush and grind using pestle and mortar into a fine powder. Figure 3.8 shown the process of treated kenaf powder grind into fine powder using pestle and mortar. The treated powders were kept in airtight container before use.


(a) (b) (c) (d)

Figure 3.8 (a) Kenaf powder treated with NaOH + Silane (b) Kenaf powder treated with NaOH (c) Dried Kenaf Powder Grind using pestle and mortar (d) Crushed treated kenaf powder

3.2.2 Preparation of Matrix (r-PP)

The preparation of recycled polypropylene is based on previous studies done by Grigore (2017). The first step, polypropylene (PP) granules are provided in Polymer Lab at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia Melaka). The granule went through one time extruding process using extruder machine with the parameter as shown in Figure 3.9 to replicate the recycled or used PP. For the final step, the PP was put into crusher machine (Figure 3.10(b)) to crush the PP into ganulate or pellet size for the fabrication process. The process flow for preparation of r-PP was demonstrated in Figure 3.9. Figure 3.10(a) shown the extruding process.

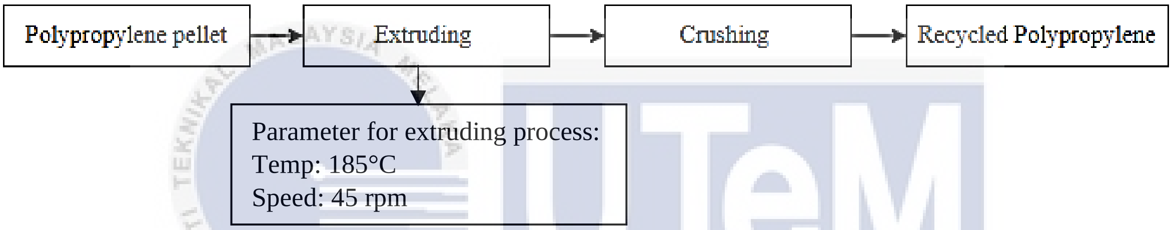


Figure 3.9 Preparation of r-PP

Figure 3.10 (a)Extruding Machine (b) Crusher Machine

3.2.3 Surface Treatment Characterisation by Fourier Transform Infrared Spectroscopy (FTIR)

For the surface modification, the Fourier Transform Infrared Spectroscopy (FTIR) was used to study the surface modification and bonding of the r-PP based composites. After the preparation is done, the powder natural fibre going through FTIR machine for characterisation using the attenuated total resistance (ATR) method. FTIR is a very effective analytical technique for identifying functional groups and the characterisation of covalent bonding information. The spectrum of the material will be obtained with the help of an infrared spectrometer (*JASCO FT/IR – 6100*) as shown in Figure 3.11, in *Nano Material Technology Lab (Raman Machine Room)* at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka).

Figure 3.11 FTIR Machine (JASCO FT/IR-6100)

Based on the frequencies at which the material absorbs infrared light and the strength of those absorptions, the substance's absorbance of infrared light at distinct frequencies provides a unique "spectral fingerprint". The spectral scan (absorbance or transmittance) that results is generally particular to a material class. This experimental will use ASTM E168, ASTM E1252 standard (ASTM International, 2021)

3.3 Design of Experiment (DOE)

For the NFRC composition, r-PP was used as the matrix, while KF as the reinforcing filler. The composition of NFRCs has been charted in Table 3.1. About 10wt.%, 20wt.%, 30wt.%, and 40wt.% filler loadings were for the weight percentage of fibre added in the r-PP based composites. As for the treatment, one third of the sample were left untreated, and the rest will be treated with NaOH and NaOH+Silane. For the sizes, the NF were sieved into the sizes of 62µm.

Table 3.1 Parameters for r-PP Based Composites Sample Preparation

Matrix	**Filler (Fibre types)**	**Chemical Treatment**	**Fibre Size (µm)**	**Filler Loading (wt.%)**
r-PP	1) KF	1) Untreated 2) NaOH Treatment (10% NaOH) 3) NaOH + Silane (10% NaOH + 3%Silane)	1) 62	1) 0 2) 10 3) 20 4) 30 5) 40

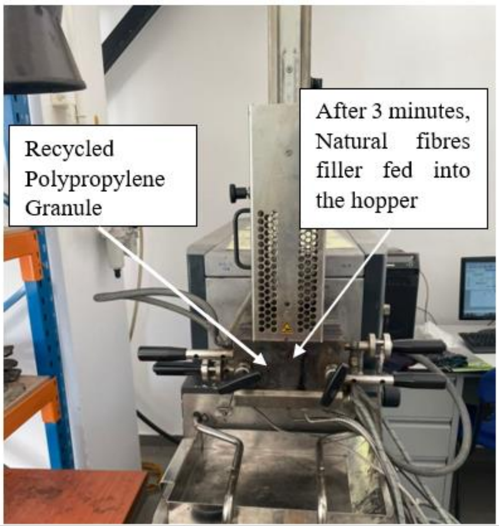
The samples were tested based on different compositions as shown in Table 3.2. In total, there were about 12 different samples from samples variations. In addition, a sample of r-PP with 0wt% reinforced filler was declared as a control sample. Overall, 13 samples were taken into consideration for the proposed testing.

Table 3.2 Experimental Composition

Matrix	**Reinforced Filler**			
	Natural Fibre	**Fibre Loading (wt.%)**	**Treatment**	**Size (µm)**
r-PP	KF	10	Untreated, U	62
		20		
		30		
		40		
		10	NaOH, N	
		20		
		30		
		40		
		10	NaOH + Silane, NS	
		20		
		30		
		40		
	-	0	Control Sample	-

3.4 Fabrication Process

Based to the previous study utilised with r-PP/KF composites of different composition were prepared by an internal mixer with temperature of 185°C which is above melting point of PP (171°C). The mixer was run for 10 min with the speed of 50rpm. The composition will be integrated with reinforcement filler with 0wt.% as control sample and 10wt.%, 20wt.%, 30wt.% and 40wt.% respectively. Figure 3.12 show the illustration of melt blending operation by using and internal mixer.



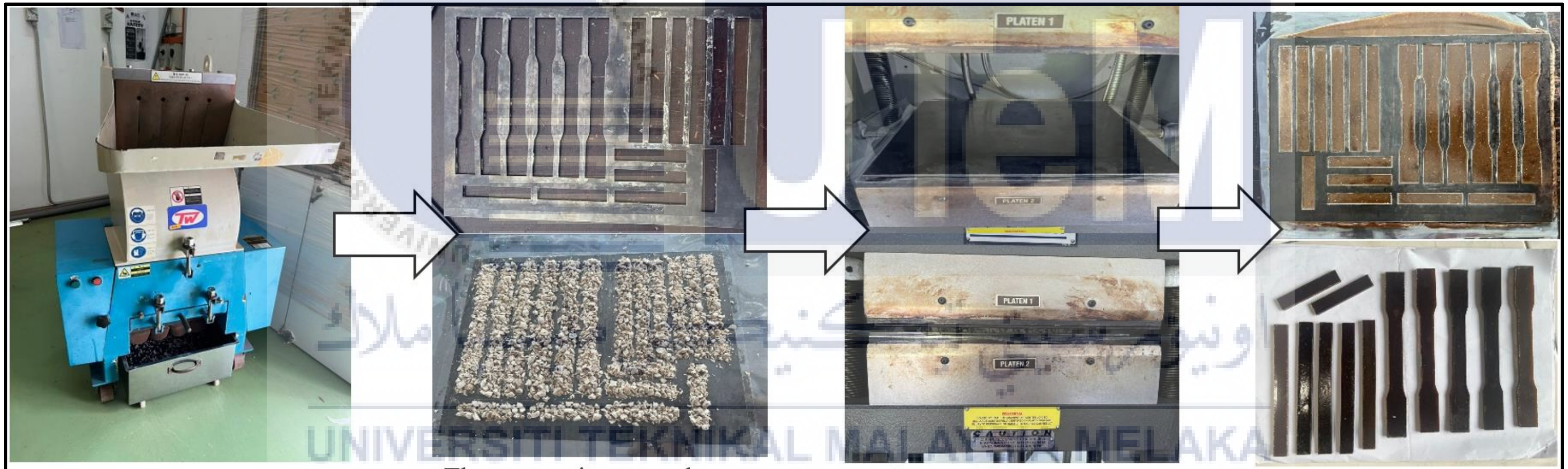
Sizes	62µm
Filler Loadings	0wt.%, 10wt.%, 20wt.%, 30wt.%, 40wt.%
Temperature	185°C
Duration	10 min
Speed	35rpm

Figure 3.12 Melt Blending Method using Internal Mixer Machine

Figure 3.12 show the illustration of melt blending principle and parameters. The fillers were added after r-PP has melted for better bonding on the fibre-matrix. Figure 3.13 show the machine that will be used in this study which is Haake Rheomix OS located at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka) in Polymer Lab.

Figure 3.13 Haake Rheomix OS (Internal Mixer Compounding Machine)

Figure 3.14 depicted the flow process of hot compression moulding process. For the compression molding, the parameters were taken from studies done by Radzi et al (2018). After the composites has been blend using melt blending compounding machine, the composites were crushed using crusher at least three times to have a fine granule. Next, the granules are then filled into the mould before putting onto the hot compression machine plate. The parameter for the machine as shown in Table 3.3. Finally, after the sample has been cooldown. The sample are taken out from the mould. Then the fabricated composited KF/r-PP sample were going through experimental testing.



Crushed at least three time to have fine granules

The composites granules are then filled into the mould

The mould then put onto compression moulding

The sample are taken out from the mould

Figure 3.14 Flow process of hot compression moulding

Table 3.3 Parameter of Hot Compression Moulding Machine

Compression Moulding Parameter	
Preheat Temp	185°C
Preheat Duration	10mins
Compressed Temp	185°C
Compressed Pressure	3000psi
Compressed Duration	10 mins
Cooling Pressure	3000psi

3.5 Testing Method

For this research, there are three standard methods that were used to for characterisation, which are mechanical test, and physical test. ASTM standards are used as the standard for the proposed testing.

3.5.1 Mechanical Testing

There are three important mechanical testing that was carried out in this study, which are tensile, impact and flexural tests. All the testing carried out in this research are in compliance to the ASTM standard, which was summarised in Table 3.4.

Table 3.4 ASTM standard used for various mechanical testing

Mechanical Testing	Standard
Tensile	ASTM D638
Impact	ASTM D4812
Flexural	ASTM D790

3.5.1.1 Tensile Strength

Tensile test was conducted in *Nano Material Technology Lab (Performance Testing Area)* at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka) by using the Universal Testing Machine (SHIMADZU AGS-X 20kN +500) shown in Figure 3.18

with a 20kN load cell. This test was used to determine the amount of force needed to break a sample specimen and how far the sample stretches or elongates before reaching the breaking point. The specimen for tensile testing is required to be cut refer to the ASTM D638 which in accordance to use type 1 tensile bar as shown in Figure 3.15. Three samples were cut to perform this test; the crosshead speed was maintained at 5 mm/min. The measurement has been set at 50 ± 5 % relative humidity and 23 ± 1 ° C room temperature (ASTM D638).

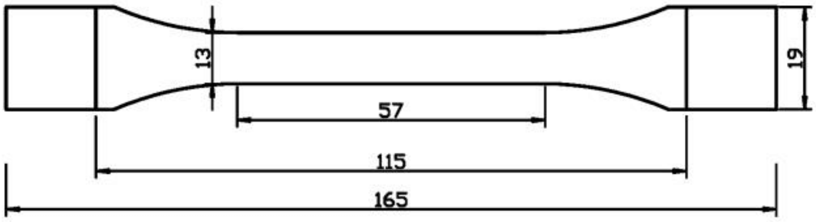


Figure 3.15 Dimension for Type 1 Tensile Bar

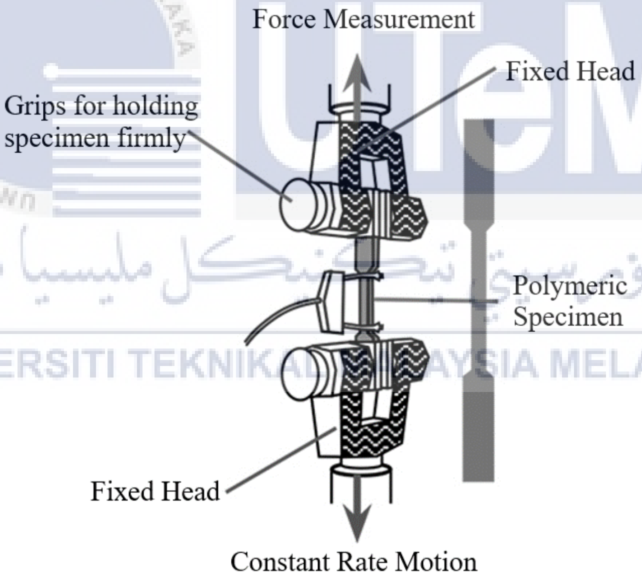


Figure 3.16 Illustration of tensile machine mechanics (Beodeker, 2015)

The illustration of the machine’s working principle was shown in Figure 3.16. Specimens are put in the universal tester's grips at a predetermined grip separation and pulled until failure occurs. The material specification determines the test speed for ASTM D638. Elongation and tensile modulus are measured using an extensometer (Intertek, 2021). Equation 3.2 and 3.3 can be used to compute the tensile strength and tensile modulus respectively. Figure 3.17 shows the setup for the tensile testing on the Universal Testing Machine.

$$Tensile\ Strength\ (MPa) = \frac{Pulling\ force\ (N)}{Sample\ thickness(mm) \times Sample\ \ width(mm)} \qquad \text{Equation 3.2}$$

$$Tensile\ Modulus\ (MPa) = \frac{Stress\ (Pa)}{Strain\ Difference} \qquad \text{Equation 3.3}$$

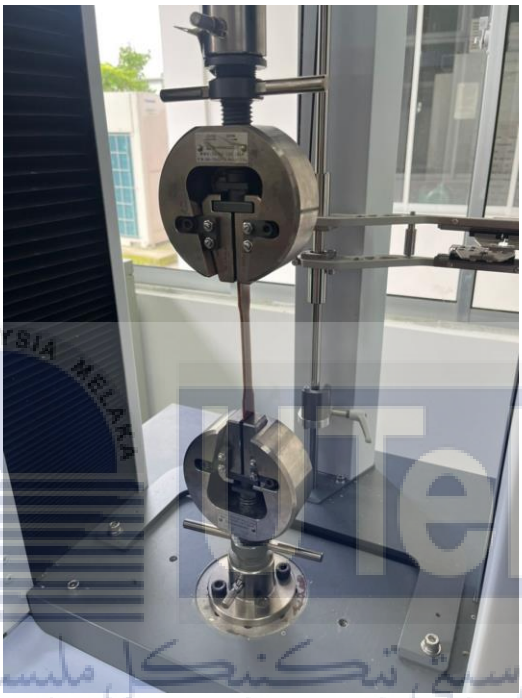


Figure 3.17 Tensile Testing

3.5.1.2 Flexural Strength

The flexural test is used to determine the amount of force required for a beam to bend under three-point bending. Since the physical properties of several materials, particularly thermoplastics are influenced by room temperature, it was essential to test materials at temperatures representative for their intended end use environment. (Intertek, 2015).

Flexural testing wase conducted in *Nano Material Technology Lab (Performance Testing Area)* at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka) The specimens for flexural tests were cut by referring to ASTM D790 at relative humidity of 50 ± 5 % and temperature of 23 ± 1°C by using Universal Testing Machine (SHIMADZU

AGS-X 20kN +500) shown in Figure 3.18 with a 5kN load cell. Three to five samples are needed to be cut to conduct this test; the crosshead speed was maintained at 2 mm/min. The length of the support span is set with a ratio of 16:1 to the sample thickness (ASTM D790). The specimen size was in accordance with ASTM standard is 3.2mm x 12.7mm x 150mm (0.125" x 0.5" x 5.0") as shown in Figure 3.19.

Figure 3.18 Universal Testing Machine (SHIMADZU AGS-X 20kN +500)

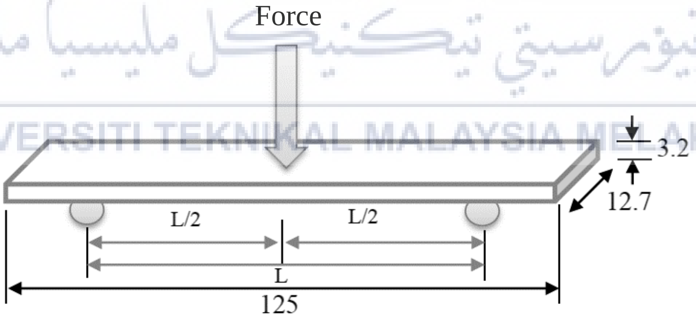


Figure 3.19 Dimension and illustration for flexural specimen

A three-point bend was formed when the specimen's loading nose is used to apply pressure to the specimen's centre. The ASTM D790 test is over when the specimen reaches a deflection of 5% or when the specimen reaches breaking point before achieving a deflection of 5%. Figure 3.20 shows the setup for the flexural machine.

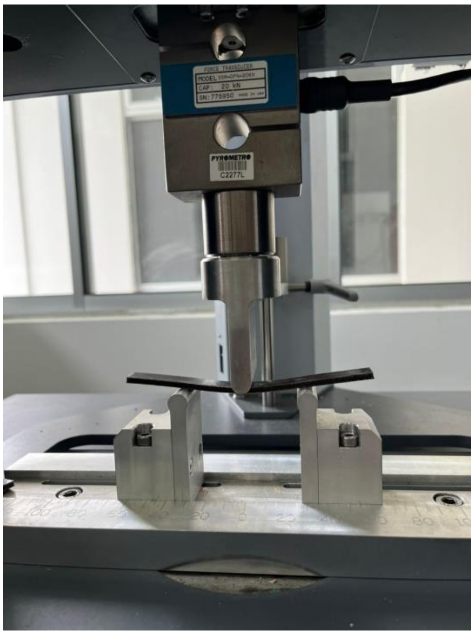


Figure 3.20 Flexural testing

3.5.2 Physical Testing

The physical characteristic that was tested in this research is moisture absorption to find out the hydroscopic nature of the composites. The density of the r-PP based composites are also evaluated in this testing. The ASTM standard that been used for this study is shown in the following table.

Table 3.5 ASTM Standards for Physical Testing

Physical Testing	Standard
Water Absorption	ASTM D570
Density	ASTM D792

3.5.2.1 Moisture Absorption

Under specified conditions, the amount of water absorbed can be determined by conducting a water absorption test. Natural fibres are hydrophilic, which means they absorb moisture. Equation 3.4 was used to compute the weight percentage gained from moisture absorption. The test was conducted for seven days according to the standard ASTM D570.

$$W\% = \frac{Wt - Wo}{Wo} \times 100$$ Equation 3.4

where, W% is the moisture content, Wt is the weight after immersion, Wo is the original weight of the specimen.

Figure 3.21 show the water absorption test. The specimens were immersed in water for seven days under room temperature. The weight of the specimens were calculated to obtain the result.

Figure 3.21 Water Absorption Test

3.5.2.1 Density

The density test is determined by the weight per unit volume of the sample. The sample was weighed with an electronic balance and the dimensions was measured with a vernier calliper. By using Archimedes' principle, we can calculate the density of the polymer. The calculation is shown in Equation 3.5, where m is mass and v are volume.

$$Density, \rho = \frac{m}{v}$$ Equation 3.5

Densimeter was used to measure the density of the composites are clearly shown in Figure 3.22.

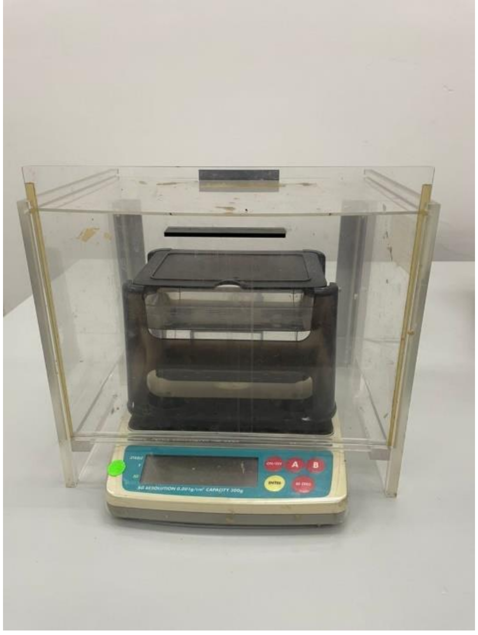


Figure 3.22 Densimeter

3.5.3 Morphological Characteristics by Scanning Electron Microscope (SEM)

In this study, to identify the sample's morphological surface fracture of the r-PP/KF after tensile testing, scanning electron microscope (SEM) was used as an instrument to examine the polymer composites. While for the chemical interaction, Fourier Transform Infrared Spectroscopy (FTIR) was used to study the surface modification and bonding of the r-PP based composites.

A scanning electron microscope (SEM) scans the fractured surface with a directed electron beam. The samples for this study were originated from the prior tensile test. After applying a coating to the sample was performed using SEM, model *Zeiss Evo 50* as shown in Figure 3.23, that was investigate the morphology of tensile fractured surfaces using a 10kv acceleration voltage. The machine is located in *Nano Material Technology Lab (SEM Machine Room)* at Fakulti Kejuruteraan Pembuatan (Universiti Teknikal Malaysia, Melaka)

Figure 3.23 SEM Machine (Zeiss Evo 50)

3.6 Summary

For this chapter, the methodologies were proposed to determine the NFRC's mechanical, and physical properties with all the proposed experimental testing. The primary purpose for the methodology is to determine the effect of r-PP/KF surface treatment to the mechanical, and physical, properties. This method is widely used in experiment practices with the guide of literature reviews that has been done and all the experiment standards are in accordance with the ASTM standard.

CHAPTER 4

RESULT AND DISCUSSION

This chapter summarises the results analysis and related discussions on all experimental data findings acquired from different testing and observations. The scientific results were thoroughly examined and analysed, with additional support from earlier research to strengthen the explanation and tie the findings to relevant theoretical frameworks. All tables, graphs, and figures, as well as the micrograph, are well portrayed and presented to aid in understanding and enhance the discussions on findings.

4.1 Overview of Result and Discussion

The main purpose of this research is to investigate the effect of Effects of kenaf fiber surface treatment and loadings to the mechanical properties of recycled polypropylene composites. For the NFRC composition, r-PP was used as the matrix, while KF as the reinforcing filler. The composition of NFRCs used were 10wt.%, 20wt.%, 30wt.%, and 40wt.% filler loadings. As for the treatment, one third of the sample were left untreated, and the rest was treated with 10% NaOH solution and 10% NaOH + 3% Silane solution. For the sizes, the NF were sieved into the sizes of 62µm. In total, there were about 12 different samples from samples variations. In addition, a sample of r-PP with 0wt% reinforced filler was declared as a control sample. Overall, 13 samples were taken into consideration for the proposed testing. Then, the sample are taken into two type of testing which were mechanical and physical testing. In addition, three sample which are the control, the best and the worst sample are selected for fracture morphological analysis by using SEM to evaluate the effect of surface treatment and loadings to the r-PP/KF composites.

4.2 FTIR Analysis on Treated and Untreated Kenaf Powder

Figure 4.1 depicted the spectra of untreated, treated with NaOH only and also treated with NaOH+Silane KF. FTIR spectroscopy is a useful technique to study the functional groups of both untreated and treated kenaf fibre and to monitor the effect of fibre treatment and chemical changes of the lignocellulosic fibre before and after the treatment (Kamarudin et al., 2018). When kenaf fiber was treated with NaOH, some impurities likes wax, lignin, and hemicellulose were removed from kenaf fiber resulting in increased intensity of all functional groups (Nimanpure et al., 2019).

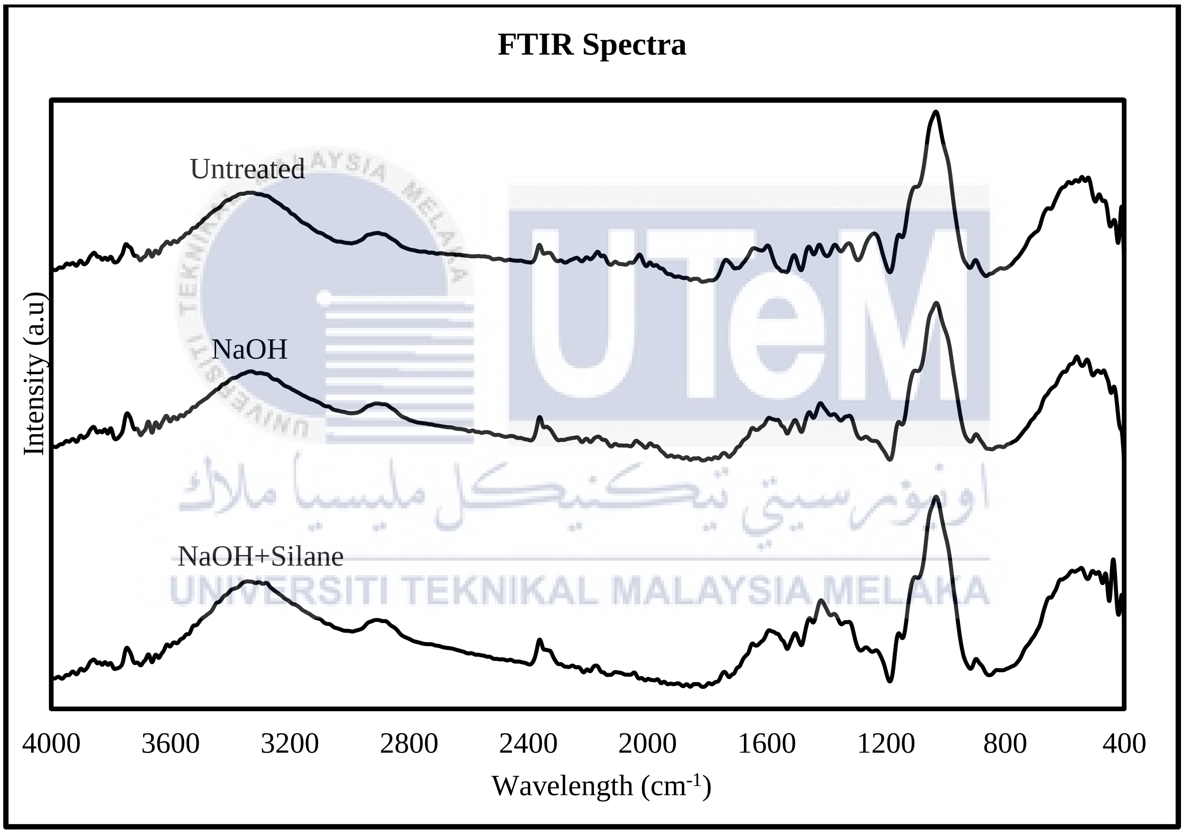


Figure 4.1 FTIR Spectra of different treatment on kenaf fibres

To find out more on the natural fibre, we separated the spectrum in 6 different zone with the corresponding functional groups based on research done by Bakri & Jayamani, (2016). Table 4.1 summarized the functional group with their dominants for each bond. Each zone has been identified with the functional groups, possible compound and predominant bond. By marking this zone in the spectrum, we can analyse the different peak point and the intensity of the zone from the sample to the example done by previous researchers. Table

4.1 summarized the functional group where some of the groups were the predominant bonds of the specific fibre constituents.

Table 4.1 Summarized functional groups with their dominants for each band (Jayamani et al., 2020)

Z	Functional Group	Possible compound	Predominant bond
1	O-H Stretching	Hydroxyl group of cellulose, hemicellulose and waxes, Phenolic and aliphatic hydroxyl groups of lignin	Cellulose
2	C–H stretching	Aliphatic and alkyl compounds of cellulose, Methyl groups of hemicellulose, Methoxyl groups of lignin and methylene groups of waxes	Hemicellulose
3	C=O stretching	Carbonyl ester and carboxyl of carboxylic acid of hemicellulose, Carbonyl aldehyde or ketone, and carboxyl of carboxylic acid of lignin, Carboxyl ester of pectin and carbonyl ester of waxes	-
4	O–CH3, O–H and C–H bending	Methoxyl groups of lignin Cellulose, hemicellulose and lignin	Lignin
5	C–O–C stretching, C–C stretching	Cellulose, hemicellulose, lignin, pectin and waxes Aromatic rings of lignin	Lignin
6	C–O stretching and deformation	Alcohol groups of cellulose Aliphatic alcohols and ethers of lignin Pectin	Cellulose

The result of the FTIR spectra above are based on the 6 zones that have been observed. Both samples had approximately similar wavelengths, except for their peak intensity occurring at OH stretching and C-H stretching. The variation in intensity from Zone 1 to Zone 6 is seen in treated and untreated KF sample. Figure 4.2 depicted the comparison of spectra of FTIR for treated and untreated KF, and Table 4.2 highlighted the peak of each zone related to functional group of KF

When compared to treated sample, untreated sample has a lower intensity at the Z1 peak, which is located at 3324.68cm^{-1} while for treated KF with NaOH only and treated with NaOH+Silane showed 3330.46cm^{-1} and 3342.46cm^{-1} respectively. This broad peak was found in both untreated and treated KF, this peaks are corresponds to O-H frequency (Z1), while the peaks at 2904.27cm^{-1}, 2910.06 cm^{-1} and 2906.20 cm^{-1} for untreated, treated with

NaOH, and treated with NaOH+Silane respectively are mostly caused by C-H stretching (Z2) of hydrocarbon in the sample. In case of untreated kenaf fibre, the broad peak at Z1 was observed due to the presence of CH_2 symmetric (wax). When kenaf fibre treated with NaOH, the peak was sharper which indicates that some amount of wax had been removed from kenaf fibre (Nimanpure et al., 2019). The untreated sample showed a vibration peak of 1729cm^{-1} corresponds to a C=0 stretching vibration (Z3) while both sample for treated has completely gone indicating the treatment eliminates the peak. While for zone 4, untreated sample showed the peak of 1423.21 cm^{-1} occurred in the spectra, but both treated samples showed that the peak has shifted to 1419.35cm^{-1} and 1417.42cm^{-1} respectively and shown that the intensity had increased. Then, untreated sample showed a vibration peak of 1240cm^{-1} and NaOH treated sample showed a vibration peak of 1321cm^{-1}, which corresponds to a C-O C stretching vibration (Z5) while the peak in NaOH+Silane treated sample has gone indicates the lignin within the NaOH+Silane treated fibre has been eliminated. For C-O stretching and deformation (Z6), the values for untreated is 1031.73cm^{-1} and NaOH and NaOH+Silane treated sample has the peak of 1029.80cm^{-1} and 1031.73cm^{-1} respectively.

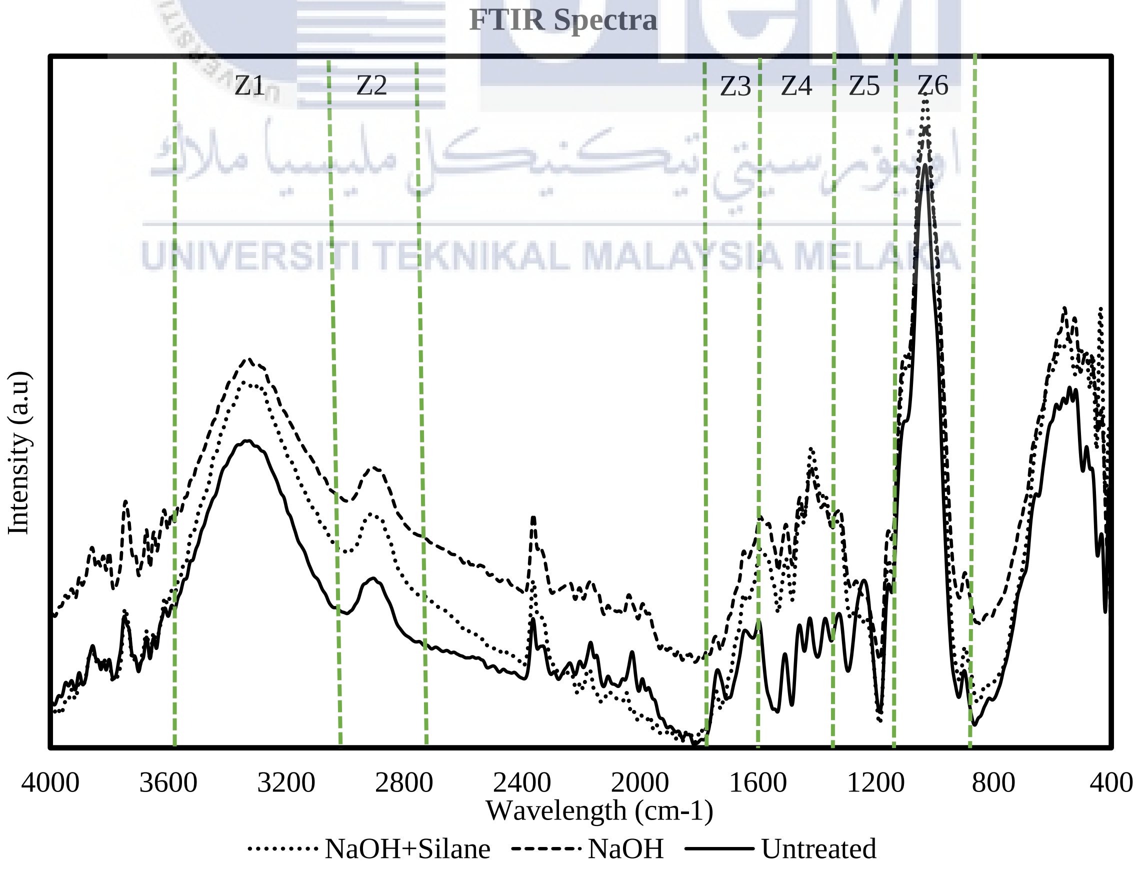


Figure 4.2 Comparison between treated and untreated kenaf fibres

Table 4.2 Functional groups of treated and untreated sample of KF

Zone	Z1	Z2	Z3	Z4	Z5	Z6
Functional Group	O-H (Stretching)	C-H (Stretching)	C=O (Stretching)	O-CH_3 (Deformation)	C-O-C, C-C (Stretching)	C-O (Stretching and Deformation)
Untreated	3324.68	2904.27	1735.62	1423.21	1240	1031.73
NaOH	3330.46	2910.06	-	1419.35	1321	1029.80
NaOH +Silane	3342.46	2906.20	-	1417.42	-	1031.73

4.3 Evaluation on Tensile Properties of Kenaf Fibre Reinforced Composites

The variation in tensile strength of NFRC with different treatment are presented in Figure 4.3. It is apparent that when the filler loadings are increased, the tensile strength has declined dramatically. The increase in the number of stress concentration sites caused by the addition of fibre is thought to be responsible for the decrease in tensile strength with higher kenaf loading. As a result, increasing the fibre content is assumed to have weakened the interfacial mechanics between the fibres and resin, resulting in an increase in the number of stress concentration sites. Poor adhesion is best explained by considering worst fibre wetting by the matrix because of various contaminants on fibre surface. It was corresponded that the natural fibre's hydrophilic character, as opposed to thermoplastics' hydrophobic nature had worsen the matrix-fibre interaction (Ardekani et al., 2014). The existence of entrapped air or moisture content at the fibre surface, in the form of a boundary layer, has prevented the fibre surface from making good contact with the resin. Due to lesser surface area available, the roughness of the fibre surfaces is correlated to a lower binding strength. The modest degree of fibre surface roughness had resulted in a weaker interfacial sites, lowering shear strength (El-Shekeil et al., 2012).

Kenaf fibre with 10wt% of treated NaOH shows the highest tensile strength among all other compositions. The slightly decreased in tensile strength from controlled sample shows that the treatment has negative impact to the KF. But untreated KF shows the lower tensile strength value as compared then the treated with NaOH. This shows that the treatment had successfully enhanced the mechanical properties of KF. On the other hand, the sample treated with NaOH, and silane shows drastically decreased in the tensile strength indicates that the treatment has not effective to improve the mechanical properties of kenaf fibre.

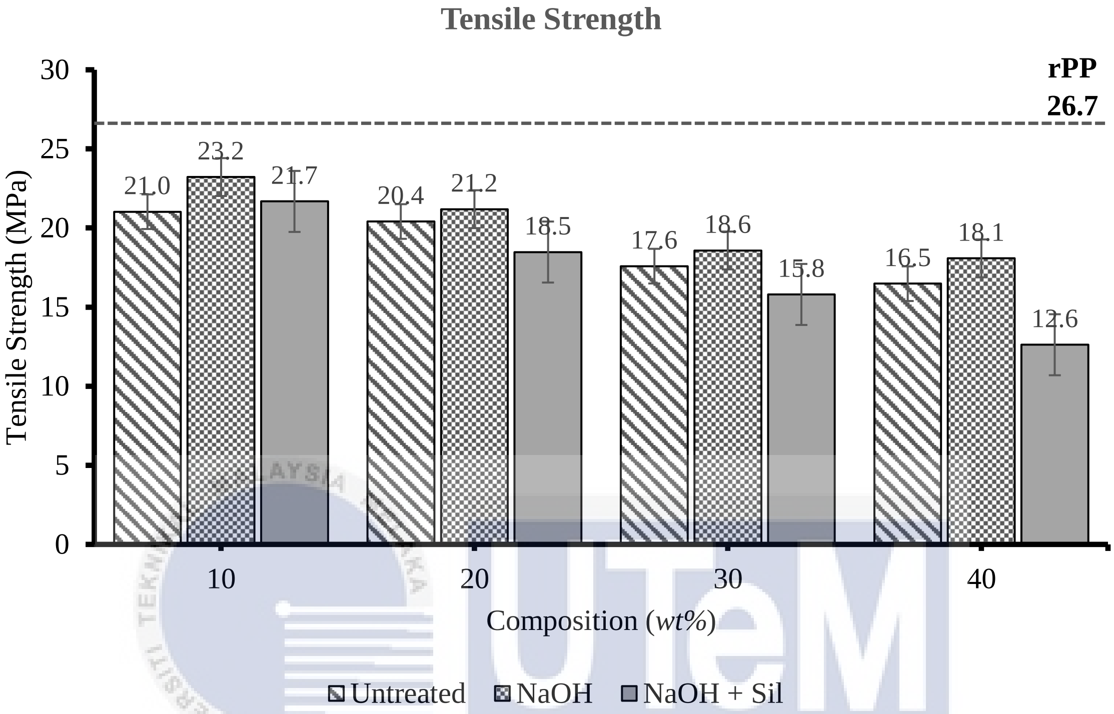


Figure 4.3 Tensile Strength of different composition and treatment of Kenaf Fibre reinforced composites

Figure 4.4 shows the tensile modulus of different composition and treatment of kenaf fibre reinforced composites. The result for tensile modulus shows a similar pattern from the result obtained for tensile strength. KF treated with NaOH has higher modulus compared to the untreated kenaf fibre.

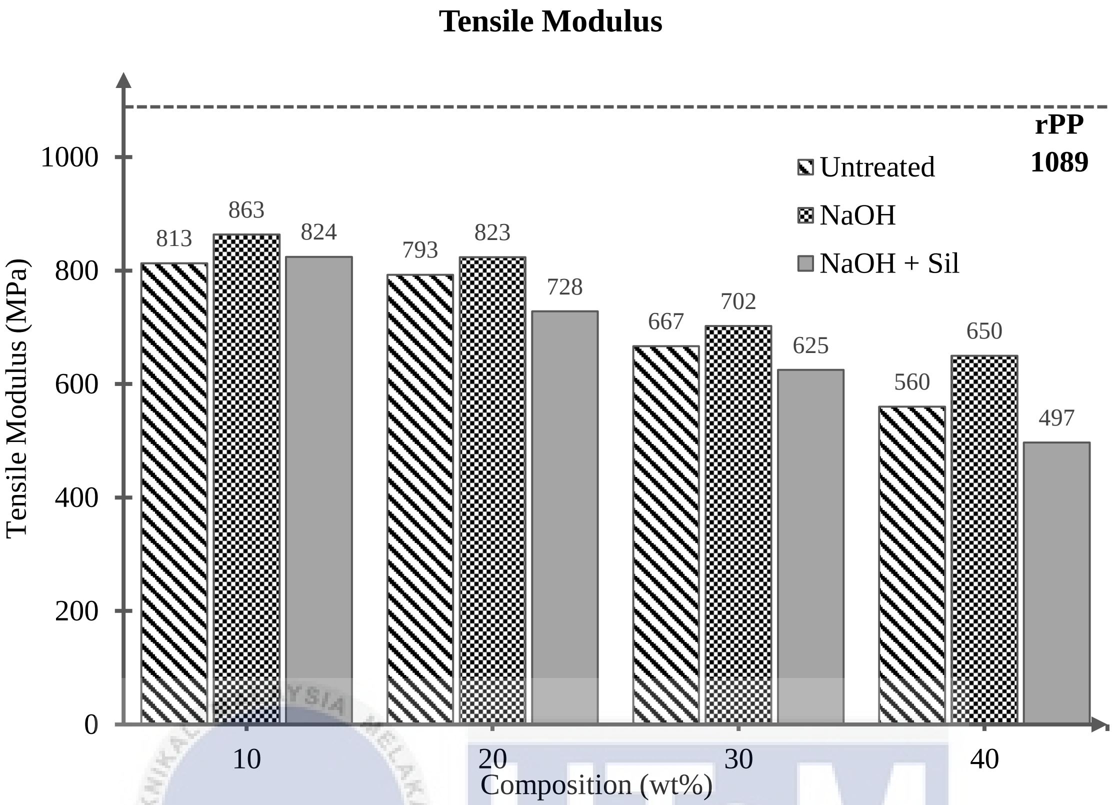


Figure 4.4 Tensile Modulus of different composition and treatment of Kenaf Fibre reinforced composites

Figure 4.5 shows the values of elongation at break for treated and untreated kenaf fibre reinforced composites at different filler loadings. From Figure 4.5, by increasing the filler loading had reduced the elongation at break for all the sample groups. For samples containing treated kenaf, the elongation at break was lower than those containing untreated kenaf. The composites with lower filler loadings show the highest elongation at break due to higher content of r-PP in the composites. The r-PP has known to have the higher elongation at break which indicates the elasticity of typical polymer. As the higher value of elongation at break, the tensile strength also increases.

The elongation at break for samples with untreated kenaf reduced from 1.8% to 0.9% while samples with NaOH treated kenaf reduced from 2.5% to 1.1% for samples with zero kenaf loading. The sample treated with NaOH+Silane reduce from 1.7% to 0.7%. By incorporating treated kenaf into NFRC, mechanical interaction was enhanced, preventing crack propagation at lower strain and making the samples less brittle. Therefore, treated kenaf samples are more likely to exhibit more elongation rather than fail at lower strain.

(Karim et al., 2018). However, the sample treated with NaOH+Silane shown a lower value compared to untreated kenaf fibres which indicated the treatment has degrade the mechanical properties of kenaf fibre at some point.

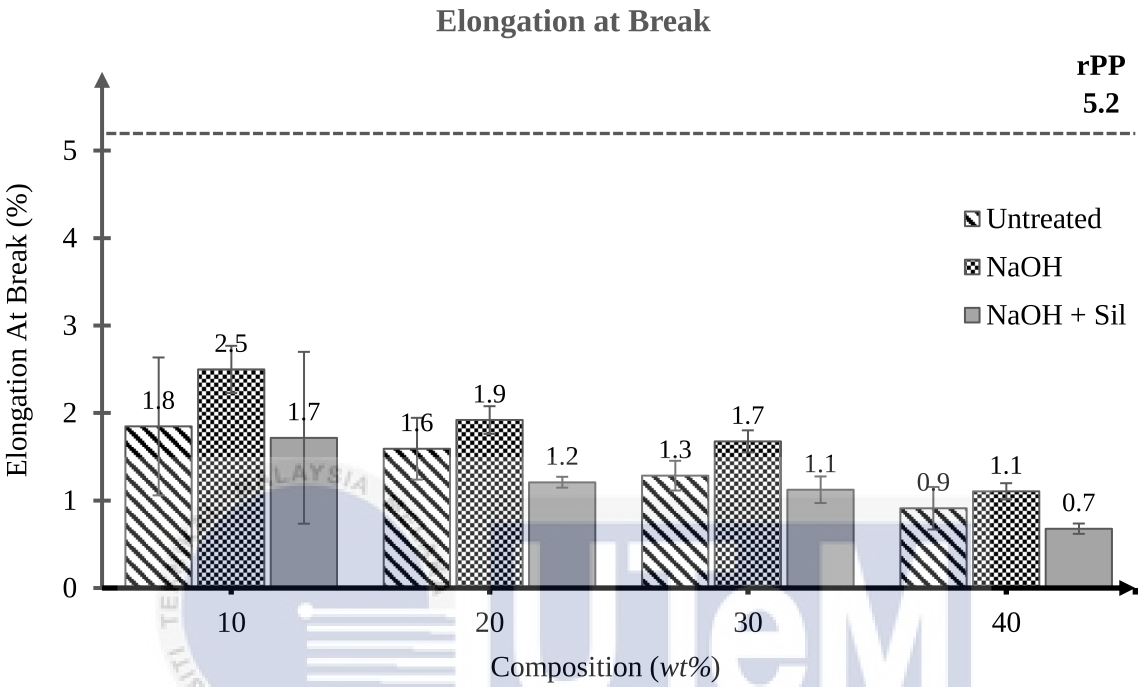


Figure 4.5 Elongation at Break for different filler loadings of treated and untreated kenaf fibres

4.4 Evaluation on Flexural Properties of Kenaf Fibre Reinforced Composites

Figure 4.6 shows the plot of the flexural strength for kenaf fibre reinforced composites. Flexural strength is a material's capacity to resist the bending forces applied perpendicular to its longitudinal axis. In general, the resistance to interlaminar failure influences the flexural characteristics of composites. As a consequence of the chemical treatment of KF, which strengthened the fibre-matrix interaction and therefore raised the interfacial bond strength and allowed for strongest adhesion at the interface, the highest flexural strengths of the composite are related to greater interfacial adhesion at the contact (Wadzani, 2019).

Similar pattern as tensile strength also shown in the flexural strength plots. The flexural strength decreased as the filler loading increased. Sample treated with NaOH only shows the higher strength compared to untreated and NaOH+Silane treated sample. The value for flexural had strength decreased from 36.1 MPa to 29.4 MPa as the filler loading increased. While for untreated sample, the strength decreased from 33.4 MPa to 27.6 MPa. In the other hand, result for sample treated with

NaOH+Silane shown the lowest value for all filler loading where the strength decreased from 32.7 MPa to 23.8 MPa. Poor adhesion between the fibre-matrix of NaOH+Silane treated kenaf may caused the weaker strength in term of flexural strength of composites. This theory later can be verified using the SEM images to find out the poor adhesion in the fibre-matrix bonding.

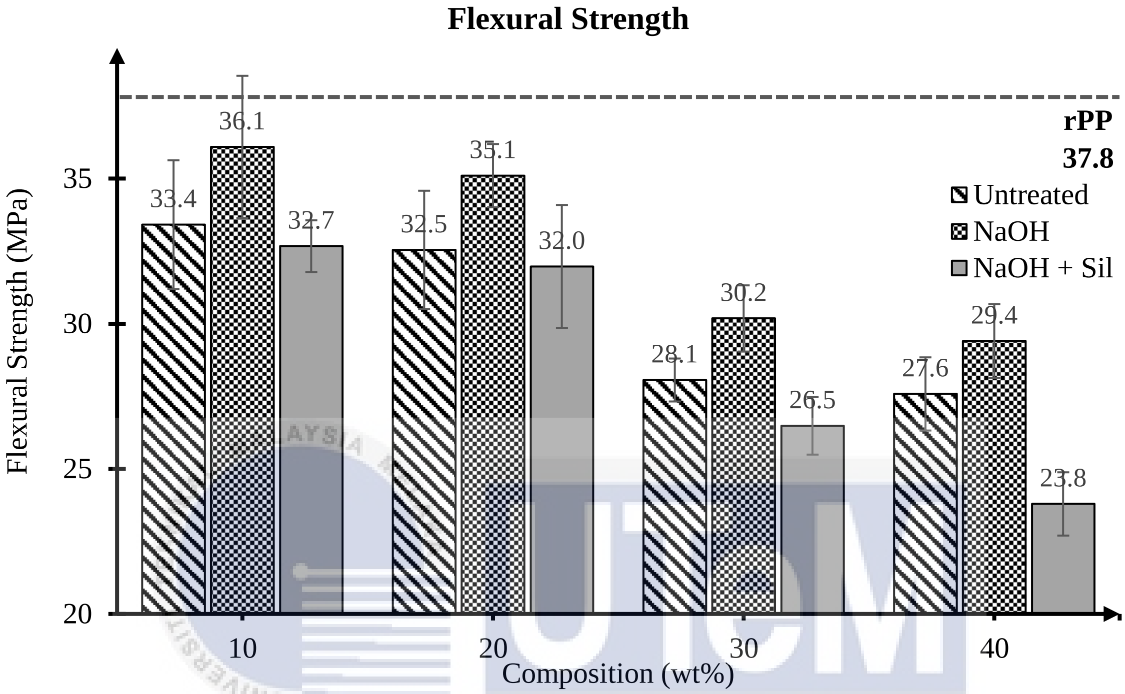
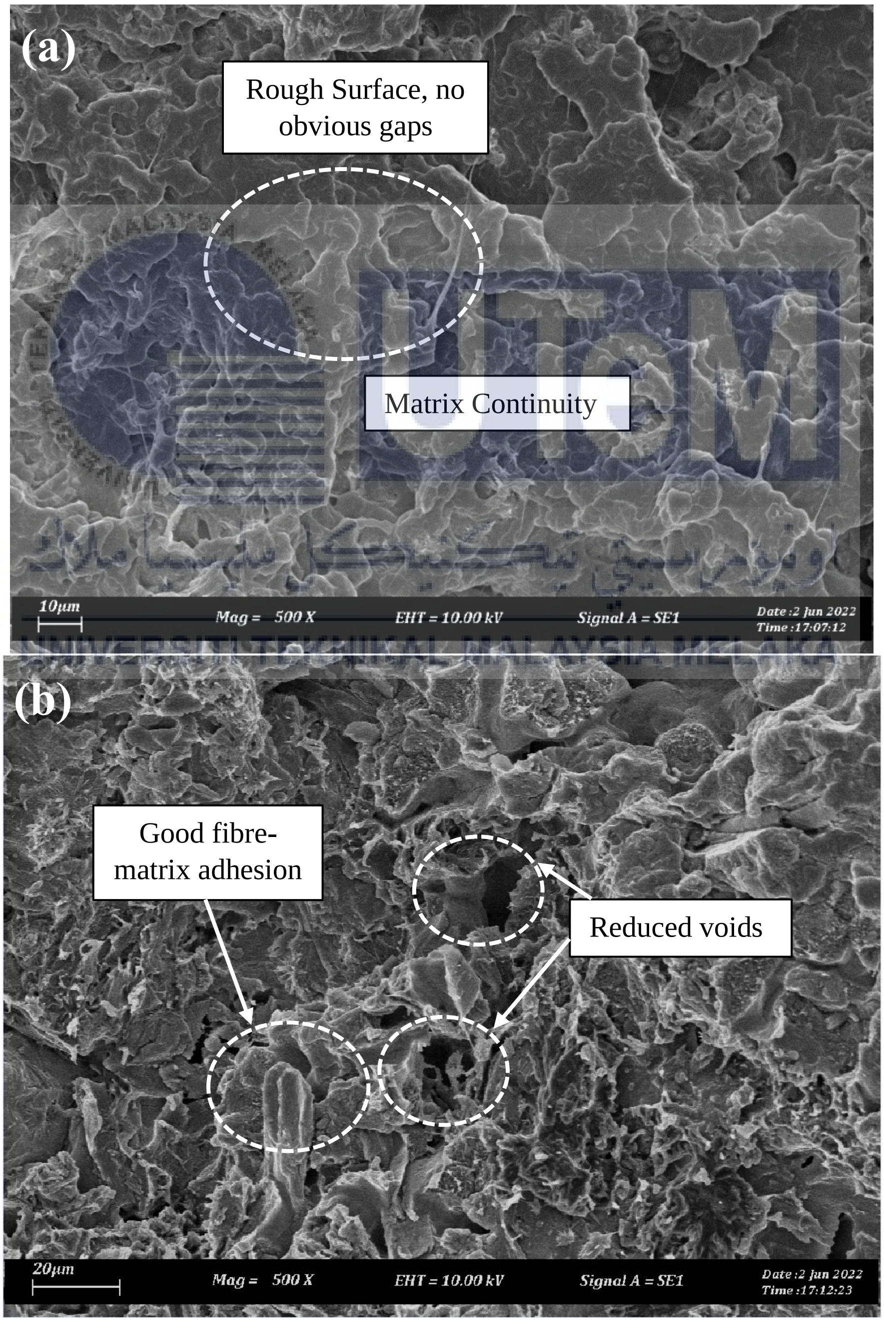


Figure 4.6 Flexural Strength of different composition and treatment of Kenaf Fibre reinforced composites

4.5 SEM Analysis on Fracture Morphologies

In order to study the failure mechanism and to examine the possible fibre-matrix mechanism, the fracture surface of composites was studied using the SEM images observation. Figure 4.7 show the SEM result of control sample, the best (NaOH 10wt%) and the worst (NaOH+Silane 40%). SEM result on r-PP sample shows that the surface is nearly smooth which indicating the matrix continuity. The micrograph of NaOH+Silane treated sample had displayed a notable gap between a fibre and a matrices. In addition, presence of aggregation and fibre breakage is visible. It was reported by Kamarudin et al., (2018), that the gaps has probably due to debonding during the mechanical testing or poor dispersion during composites preparations which indicating of weak fibre-matrix adhesion. Based on SEM results, Kenaf treated with NaOH+Silane samples had many exposed fibres pulled out from the matrix and filler related failure, NaOH treated kenaf had more embedded fibres and significantly voids had been reduced.

Interfacial bonding between fibres and matrices is essentially determined by the degree of adhesion between the fibres and the matrix. The stress transfer from the matrix to fibre has a significant impact to the ultimate performance of produces composite. Therefore, one method for modifying and enhancing the fibre–matrix interfacial bonding is the modification of the fibre surface by using chemical treatment (De Rosa et al., 2011).



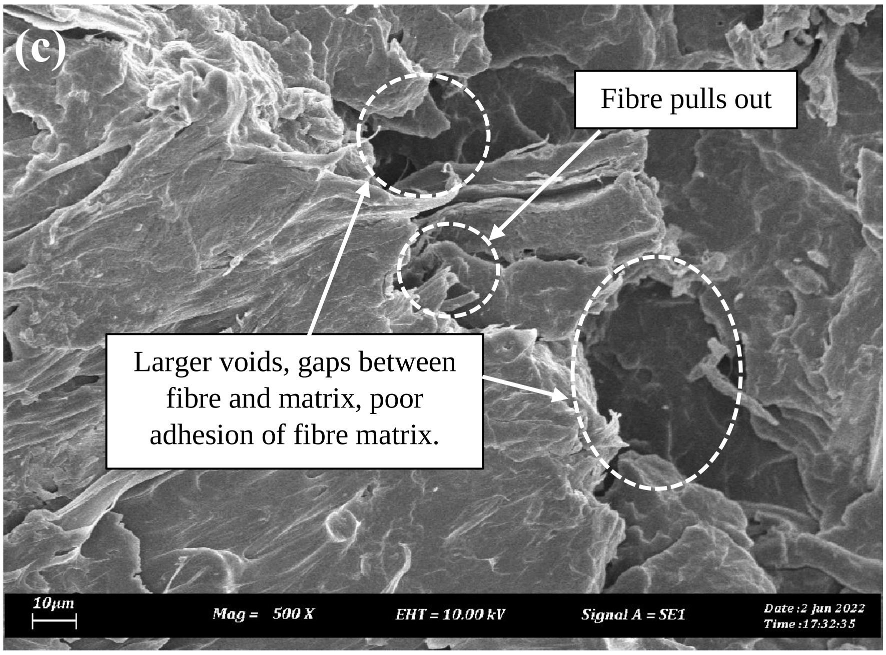


Figure 4.7 Surface Morphology of (a) Control Sample: r-PP (b) Best Sample: NaOH 10wt% and (c)Worst Sample: NaOH+Silane 40%

4.6 Water Absorption Characteristic

Water absorption result (Figure 4.8) shows a noteworthy results between the untreated and treated fibres filled composites. The measurements were taken after seven days of immersion in water. Untreated kenaf fibre are the highest rate of water absorption rate compared to both treated samples. This clearly proven the hydrophilic nature of natural fibre. For the treated kenaf fibre, both treatments shown a slightly difference in the testing results. The treatment were able to reduce the hydrophilic character of the fibres which indicates the treatment were successful. Thus, suggesting that a better adhesion with hydrophobic r-PP could be achieved.

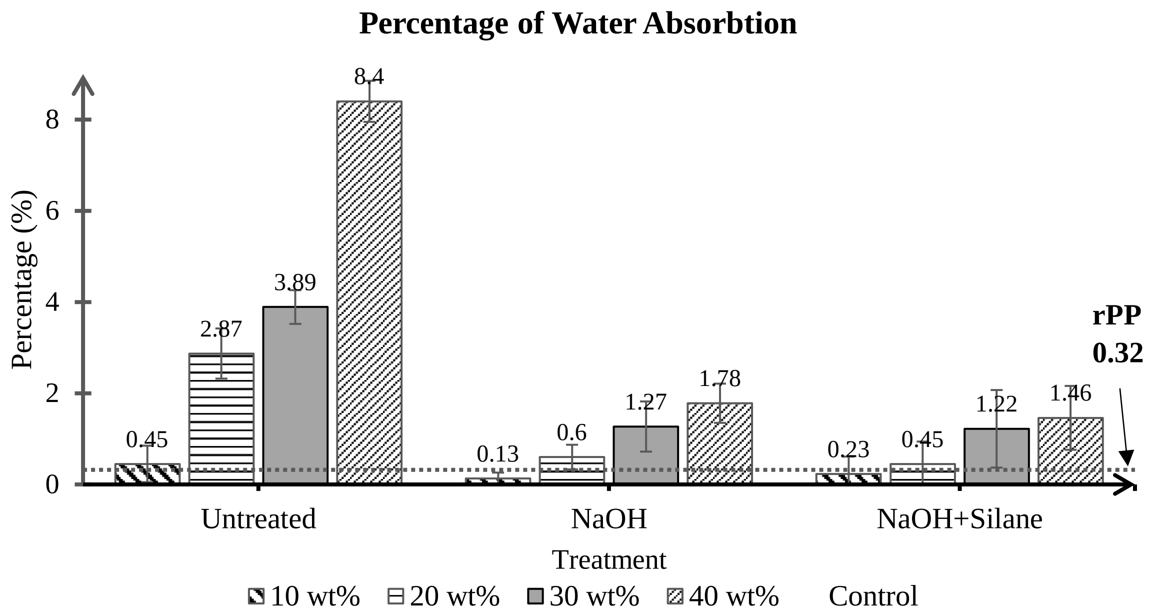


Figure 4.8 Percentage of Water Absorption

4.7 Density of Kenaf Fibre Reinforced Composites with Different Filler Loadings

The density of kenaf fibre reinforced composites is shown in Figure 4.9. From Figure 4.9, it is shown that there was an increase in density as the increasing in fibre loadings. The density of samples with untreated kenaf increased from 0.951 to 1.041 g/cm^3 while the density of NaOH treated kenaf increased from 0.917 to 1.067 g/cm^3 and kenaf treated with NaOH+Silane increased from 0.957 to 1.082 g/cm^3. For the density of r-PP, it was recorded at 0.91g/cm^3. Higher void content had resulted to a decrease resistance into water penetration, causing produced composites to be weaker. Karim et al., (2018) also reported that as kenaf loading increased, kenaf fibre contributed to an increase in mass of kenaf-reinforced composites, which led to an increase in density. However, the data obtain form the water absorption test contradict with all the other result whereby the NaOH+Silane has lower value in water absorption rate compared to the NaOH treated only. This might be due to a technical fault pertaining to the sensitivity of the weighing balance equipment, which is too sensitive to vibration from the surroundings, causing experimental data errors.

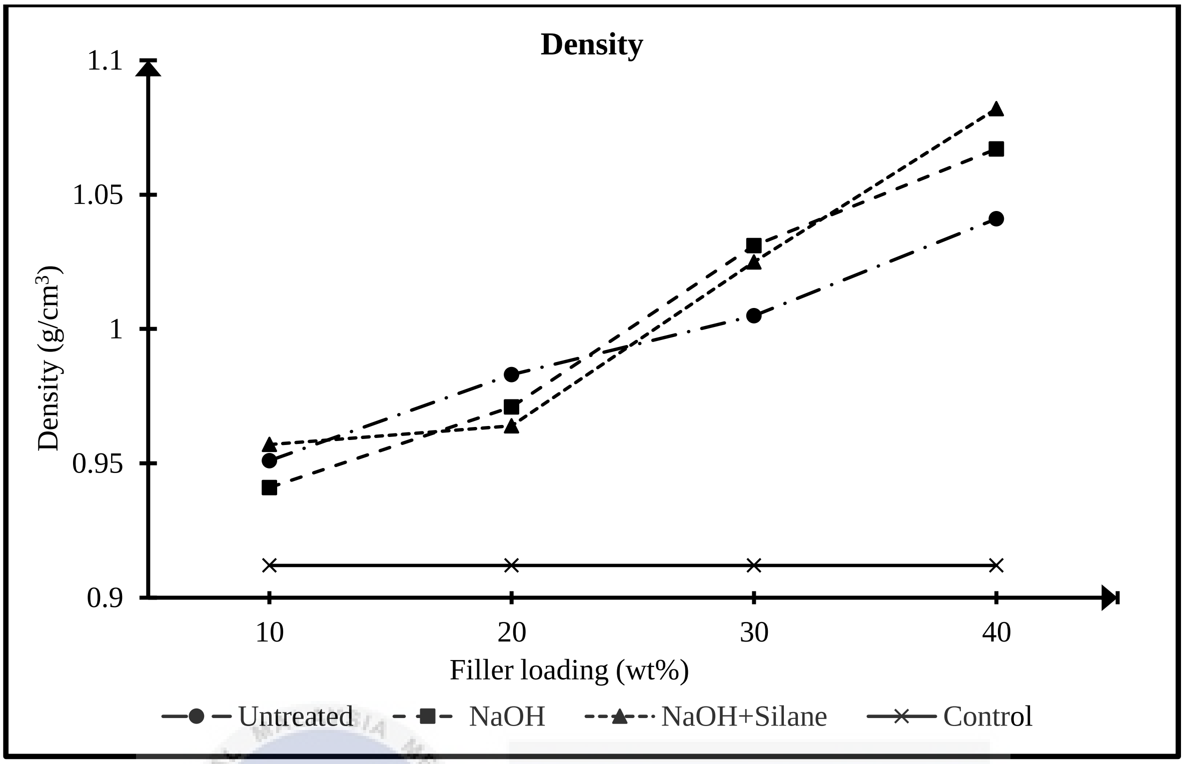


Figure 4.9 Density of Kenaf Fibre Reinforced Composites with different composition

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter focuses on the conclusion derived from the results given in Chapter 4. Furthermore, this conclusion is used to evaluate the achievement of the objectives mentioned in Chapter 1. This chapter also includes recommendations to offer some suggestions for improving the study results, and last but not least, the sustainability factor is described at the conclusion.

5.1 Conclusion

In conclusion, kenaf fibre reinforced polypropylene composites were successfully produced by using the melt mixing compounding machine and moulded by using the hot compression moulding machine.

The first objective for this research is to evaluate the success of surface treatments performed to the KF using FTIR method is successfully achieved with some highlights as the followings:

(i) FTIR spectroscopy is a useful technique to study the functional groups of both untreated and treated kenaf fibre and to monitor the effect of fibre treatment and chemical changes of the lignocellulosic fibre at before and after the treatment.

(ii) In case of untreated kenaf fiber, a broad peak at 2,910 cm^{-1} was observed due to the presence of CH_2 symmetric (wax). When kenaf fiber treated with NaOH, the peak was sharper which indicates that some amount of wax had been removed from kenaf fiber

(iii) The untreated sample showed a vibration peak of 1729cm^{-1} corresponds to a C=O stretching vibration (Z3) while both sample for treated has completely gone indicating the treatment eliminates the peak.

(iv) Then, untreated sample showed a vibration peak of 1240cm^{-1} and NaOH treated sample showed a vibration peak of 1321cm^{-1}, which corresponds to a C-O C stretching vibration (Z5) while the peak in NaOH+Silane treated sample has gone indicates the lignin within the NaOH+Silane treated fibre has been eliminated.

The second objective for this study is to study the effects of surface treatment of KF natural fibre added as filler in recycled polypropylene based composites at various loadings (0wt.%, 10wt.%, 20wt.%, 30wt.%, 40wt.%) by using several mechanical, and physical testing is successfully achieved. The summary for the significant findings that reflect the achievement of second objective are as follows:

(i) Kenaf fibre with 10wt% treated with NaOH show the highest tensile and flexural strength among all other compositions with the strength of 23.2MPa and 36.1MPa respectively

(ii) NaOH treated sample shows higher strength compared to the untreated kenaf which indicates the treatment are successfully enhanced the mechanical properties of kenaf fibre.

(iii) NaOH+Silane treatment degrade the mechanical properties of the KF due to the high content of Silane (3%) were used in this study. The properties of the composites drastically decreasing as the filler loading increased.

(iv) 10wt% NaOH treated sample has the highest value in modulus of elasticity show that the composition has high resistance to being deformed elastically.

(v) 10wt% filler loadings for all treated and untreated sample showed the highest elongation at break due to the higher content in r-PP.

(vi) For density testing, it is clear that density increase with increased in kenaf loading. Kenaf fibre contributed to an increased in mass of kenaf reinforced composites which lead to the increased in density as kenaf loading increased

(vii) 40wt% of untreated sample showed the highest water absorption rate among all the sample. It is parallel with the research done by previous study where natural fibre are hydrophilic in nature.

The fracture surface morphology of KF/r-PP composites, were observed through scanning electron microscopy (SEM) as to achieve the last objective stated for this study. It was interesting to note the following finding as to highlight the success of this study.

(i) SEM result on r-PP sample shows that the surface is nearly smooth indication of matrix continuity.

(ii) The micrograph of NaOH+Silane treated displays a notable gap between a fibre and a matrix. In addition, presence of aggregation and fibre breakage is visible due to the debonding during mechanical testing or poor dispersion during composites preparations which indicates a weak fibre-matrix adhesion.

(iii) Based on SEM result, kenaf treated with NaOH+Silane had many exposed fibres pulled out from the matrix and filler related failure, NaOH treated kenaf had more embedded fibres and significantly voids had been reduced.

5.2 Recommendation

There are 5 recommendations for further improving this study.The following are the suggestions:

(i) For further study, it is suggested that the various concentration of NaOH solution can be used to study the effect of different effect of NaOH concentration on the mechanical properties of the KF/r-PP composites.

(ii) Further studies may also be made by using different type of treatment to make comparison of effect of the treatment to the mechanical properties of the KF.

(iii) Also, conducting the study on the effect of various concentration of (3-aminopropyl) triethoxysilane treatment to the mechanical properties of KF/r-PP composites.

(iv) To have better understanding the properties of the KF/r-PP composites, thermal analysis can be made to find out the thermal properties of the composites by using TGA or DSC machine to study the thermal stability.

(v) The use of different filler sizes also can be made to investigate the effect of various sizes of natural fibre filler to the mechanical properties of r-PP based composites.

5.3 Sustainability Design and Development

It is predicted that this study will serve society by creating a new creation of improved materials that use the advantages of natural fibre polymer composites technology. This sophisticated composites derivate might be used in saving earth, for example reducing global pollution of waste, and saving marine life from wave of plastic trash. The composite reinforced with natural fibre has better degradation rate than pure plastic which lasted forever. This new candidate of unique high performance material made from natural fibre is also environmentally friendly, causing no pollution or damage to the environment or society. This innovative new material is very lightweight which can be used in many high end industries such as automotive, food and also aerospace industry. Therefore, in the event that technology is utilized or used for the automotive industry, cars that are light in weight and inexpensive might potentially be manufactured. Fuel consumption may be considerably reduced by lowering the weight of the vehicle. As a result, carbon dioxide and carbon monoxide emissions may be minimized. Furthermore, this composite material is seen to be highly promising in terms of supporting our society as well as the environment. Natural fibre is also biodegradable. Thus, it will result in some advantage in the proposed product's end-of-life attributes for specified high-end real-world applications.

5.4 Lifelong Learning

Throughout this project, time is the most common constraint to complete the study. The ability to schedule and divide time allocation for conducting the project and focusing on study are important key in successfully achieved both academic and spiritual side. Furthermore, operating machine for the first time also a challenge which can helps gaining new knowledge on how to operate the machine in a correct procedure with low supervision. Also, while waiting for available slot to use a certain machine or apparatus, filling up the time to complete other tasks or procedure for the project are vital to make sure no time are waste.

5.5 Complexity

In this study, the complexity can be found while doing the hot mixer compounding machine because the powdered KF are lightweight and easily blown away with the presences of wind and sudden movement resulting an inaccurate measurement to the composition. This complexity also happened during treatment process where the powdered KF scattering in the air when the magnetic stirrer stirred the mixture. Next, the complexity also occurred while doing moulding process. The size of crushed KF/r-PP composites are not small enough to fill the mould resulting a lot of space and bubble occurred during the fabrication process. It is advised to grind the composites into smaller sizes using smaller crusher which are not available in UTeM at the moment.

REFERENCES

Akhtar, M. N., Sulong, A. B., Radzi, M. K. F., Ismail, N. F., Raza, M. R., Muhamad, N., & Khan, M. A. (2016). Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications. *Progress in Natural Science: Materials International*, *26*(6), 657–664. https://doi.org/10.1016/j.pnsc.2016.12.004

Akil, H. M., Omar, M. F., Mazuki, A. A. M., Safiee, S., Ishak, Z. A. M., & Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials and Design*, *32*(8–9), 4107–4121. https://doi.org/10.1016/j.matdes.2011.04.008

Albert Seldon, P., & Abilash, N. (2019). Appraisal on Varied Natural and Artificial Fiber Reinforced Polymeric Composites. *Materials Today: Proceedings*, *22*, 3213–3219. https://doi.org/10.1016/j.matpr.2020.03.459

Ali, S. S., Elsamahy, T., Koutra, E., Kornaros, M., El-Sheekh, M., Abdelkarim, E. A., Zhu, D., & Sun, J. (2021). Degradation of conventional plastic wastes in the environment: A review on current status of knowledge and future perspectives of disposal. *Science of the Total Environment*, *771*, 144719. https://doi.org/10.1016/j.scitotenv.2020.144719

AlMaadeed, M. A., Kahraman, R., Noorunnisa Khanam, P., & Madi, N. (2012). Date palm wood flour/glass fibre reinforced hybrid composites of recycled polypropylene: Mechanical and thermal properties. *Materials and Design*, *42*, 289–294. https://doi.org/10.1016/j.matdes.2012.05.055

Altenbach, H., Altenbach, J., & Kissing, W. (2018). Mechanics of composite structural elements: Second edition. In *Mechanics of Composite Structural Elements: Second Edition* (pp. 1–503). https://doi.org/10.1007/978-981-10-8935-0

Ardekani, S. M., Dehghani, A., Al-Maadeed, M. A., Wahit, M. U., & Hassan, A. (2014). Mechanical and thermal properties of recycled poly(ethylene terephthalate) reinforced newspaper fiber composites. *Fibers and Polymers*, *15*(7), 1531–1538.

https://doi.org/10.1007/s12221-014-1531-y

Arifur Rahman, M., Parvin, F., Hasan, M., & Hoque, M. E. (2015). Introduction to Manufacturing of Natural Fibre-Reinforced Polymer Composites. In *Manufacturing of Natural Fibre Reinforced Polymer Composites* (pp. 17–43). Springer International Publishing. https://doi.org/10.1007/978-3-319-07944-8_2

Asim, M., Saba, N., Jawaid, M., & Nasir, M. (2018). Potential of natural fiber/biomass filler-reinforced polymer composites in aerospace applications. In *Sustainable Composites for Aerospace Applications*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102131-6.00012-8

ASTM International. (2021). *Fourier transform infrared spectrometry ASTM E168, ASTM E1252*. ASTM International. https://www.intertek.com/polymers/testlopedia/ftir/

Asumani, O. M. L., Reid, R. G., & Paskaramoorthy, R. (2012). The effects of alkali-silane treatment on the tensile and flexural properties of short fibre non-woven kenaf reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing*, *43*(9), 1431–1440. https://doi.org/10.1016/j.compositesa.2012.04.007

Bakri, M. K. B., & Jayamani, E. (2016). Comparative Study of Functional Groups in Natural Fibers: Fourier Transform Infrared Analysis (FTIR). *Futuristic Trends in Engineering, Science, Humanities, and Technology, January*, 167–174. http://www.troindia.in/proceeding/vol-1 proceeding.pdf#page=186

Balakrishnan, P., John, M. J., Pothen, L., Sreekala, M. S., & Thomas, S. (2016). Natural fibre and polymer matrix composites and their applications in aerospace engineering. In *Advanced Composite Materials for Aerospace Engineering*. Elsevier Ltd. https://doi.org/10.1016/b978-0-08-100037-3.00012-2

Begum, S. A., Rane, A. V., & Kanny, K. (2019). Applications of compatibilized polymer blends in automobile industry. In *Compatibilization of Polymer Blends: Micro and Nano Scale Phase Morphologies, Interphase Characterization, and Properties*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-816006-0.00020-7

Begum, S., Fawzia, S., & Hashmi, M. S. J. (2020). Polymer matrix composite with natural and synthetic fibres. *Advances in Materials and Processing Technologies*, *6*(3), 547–564. https://doi.org/10.1080/2374068X.2020.1728645

Beodeker. (2015). *ASTM Property Testing Overview | Boedeker*. https://www.boedeker.com/Technical-Resources/Technical-Library/ASTM-Property-Testing-Overview

Chamas, A., Moon, H., Zheng, J., Qiu, Y., Tabassum, T., Jang, J. H., Abu-Omar, M., Scott, S. L., & Suh, S. (2020). Degradation Rates of Plastics in the Environment. *ACS Sustainable Chemistry and Engineering*, *8*(9), 3494–3511. https://doi.org/10.1021/acssuschemeng.9b06635

Chegdani, F., & Mansori, M. El. (2018). Mechanics of material removal when cutting natural fiber reinforced thermoplastic composites. *Polymer Testing*, *67*, 275–283. https://doi.org/10.1016/j.polymertesting.2018.03.016

Christopher C. I. (2011). Thermoplastic Materials: Properties, Manufacturing Methods, and Applications. In *Introduction and History of the Plastics Industry*.

Chu, C. C., Chew, S. C., & Nyam, K. L. (2021). Recent advances in encapsulation technologies of kenaf (Hibiscus cannabinus) leaves and seeds for cosmeceutical application. *Food and Bioproducts Processing*, *127*, 99–113. https://doi.org/10.1016/j.fbp.2021.02.009

Chukov, D., Nematulloev, S., Zadorozhnyy, M., Tcherdyntsev, V., Stepashkin, A., & Zherebtsov, D. (2019). Structure, mechanical and thermal properties of polyphenylene sulfide and polysulfone impregnated carbon fiber composites. *Polymers*, *11*(4). https://doi.org/10.3390/polym11040684

Chung, D. D. L. (2017). Carbon Fibers, Nanofibers, and Nanotubes. In *Carbon Composites* (Second Edi, Issue 1). Elsevier Inc. https://doi.org/10.1016/b978-0-12-804459-9.00001-4

Das, T. K., Ghosh, P., & Das, N. C. (2019). Preparation, development, outcomes, and application versatility of carbon fiber-based polymer composites: a review. *Advanced Composites and Hybrid Materials*, *2*(2), 214–233. https://doi.org/10.1007/s42114-018-0072-z

De Rosa, I. M., Kenny, J. M., Maniruzzaman, M., Moniruzzaman, M., Monti, M., Puglia, D., Santulli, C., & Sarasini, F. (2011). Effect of chemical treatments on the mechanical and thermal behaviour of okra (Abelmoschus esculentus) fibres. *Composites Science and Technology*, *71*(2), 246–254. https://doi.org/10.1016/j.compscitech.2010.11.023

Delaney, P. (2013). *HOW LONG IT TAKES FOR SOME EVERYDAY ITEMS TO DECOMPOSE. - Down2Earth Materials*. https://www.down2earthmaterials.ie/2013/02/14/decompose/

Dicker, M. P. M., Duckworth, P. F., Baker, A. B., Francois, G., Hazzard, M. K., & Weaver, P. M. (2014). Green composites: A review of material attributes and complementary applications. *Composites Part A: Applied Science and Manufacturing*, *56*, 280–289. https://doi.org/10.1016/j.compositesa.2013.10.014

Dilfi K.F., A., Balan, A., Bin, H., Xian, G., & Thomas, S. (2018). Effect of surface modification of jute fiber on the mechanical properties and durability of jute fiber-reinforced epoxy composites. *Polymer Composites*, *39*, E2519–E2528. https://doi.org/10.1002/PC.24817

El-Shekeil, Y. A., & Sapuan, S. M. (2014). Effect of fiber treatment on stress-strain behavior of Kenaf Fibers reinforced thermoplastic polyurethane composites. *Applied Mechanics and Materials*, *575*, 46–49. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMM.575.46

El-Shekeil, Y. A., Sapuan, S. M., Abdan, K., & Zainudin, E. S. (2012). Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites. *Materials and Design*, *40*, 299–303. https://doi.org/10.1016/j.matdes.2012.04.003

Fiore, V., Di Bella, G., & Valenza, A. (2015). The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites. *Composites Part B: Engineering*, *68*, 14–21. https://doi.org/10.1016/J.COMPOSITESB.2014.08.025

Fried, J. R. (2003). Polymer Science & Technology. In *Pearson Education, Inc.* Pearson Education, Inc. https://doi.org/10.1039/9781847550002-00197

Gironès, J., López, J. P., Mutjé, P., Carvalho, A. J. F., Curvelo, A. A. S., & Vilaseca, F. (2012). Natural fiber-reinforced thermoplastic starch composites obtained by melt processing. *Composites Science and Technology*, *72*(7), 858–863. https://doi.org/10.1016/j.compscitech.2012.02.019

Giwa Ibrahim, S., Karim, R., Saari, N., Wan Abdullah, W. Z., Zawawi, N., Ab Razak, A. F., Hamim, N. A., & Umar, R. A. (2019). Kenaf (Hibiscus cannabinus L.) Seed and its Potential Food Applications: A Review. In *Journal of Food Science* (Vol. 84, Issue 8, pp. 2015–2023). https://doi.org/10.1111/1750-3841.14714

Grigore, M. E. (2017). Methods of recycling, properties and applications of recycled thermoplastic polymers. *Recycling*, *2*(4), 1–11. https://doi.org/10.3390/recycling2040024

Gurunathan, T., Mohanty, S., & Nayak, S. K. (2015). A review of the recent developments in biocomposites based on natural fibres and their application perspectives. *Composites Part A: Applied Science and Manufacturing*, *77*, 1–25. https://doi.org/10.1016/j.compositesa.2015.06.007

Herrera Franco, P. J., & Valadez-González, A. (2005). Fiber-matrix adhesion in natural fiber composites. In *Natural Fibers, Biopolymers, and Biocomposites*. https://doi.org/10.1201/9780203508206.ch6

Hirai, H., Takada, H., Ogata, Y., Yamashita, R., Mizukawa, K., Saha, M., Kwan, C., Moore, C., Gray, H., Laursen, D., Zettler, E. R., Farrington, J. W., Reddy, C. M., Peacock, E. E., & Ward, M. W. (2011). Organic micropollutants in marine plastics debris from the open ocean and remote and urban beaches. *Marine Pollution Bulletin*, *62*(8), 1683–1692. https://doi.org/10.1016/j.marpolbul.2011.06.004

Hisham A. Maddah. (2016). Polypropylene as a Promising Plastic: A Review. *American Journal of Polymer Science*, *January*. https://doi.org/10.5923/j.ajps.20160601.01

Ho, M. P., Wang, H., Lee, J. H., Ho, C. K., Lau, K. T., Leng, J., & Hui, D. (2012). Critical factors on manufacturing processes of natural fibre composites. *Composites Part B: Engineering*, *43*(8), 3549–3562. https://doi.org/10.1016/j.compositesb.2011.10.001

Huda, M. S., Drzal, L. T., Mohanty, A. K., & Misra, M. (2008). Effect of fiber surface-treatments on the properties of laminated biocomposites from poly(lactic acid) (PLA) and kenaf fibers. *Composites Science and Technology*, *68*(2), 424–432. https://doi.org/10.1016/j.compscitech.2007.06.022

Ibrahim, M. I., Hassan, M. Z., Dolah, R., Yusoff, M. Z. M., & Salit, M. S. (2018). Tensile behaviour for mercerization of single kenaf fiber. *Malaysian Journal of Fundamental and Applied Sciences*, *14*(4), 437–439. https://doi.org/10.11113/mjfas.v14n4.1099

Intertek. (2015). *Flexural Properties Testing*. https://www.intertek.com/polymers/testing/flexural-properties/

Intertek. (2021). *Plastics Tensile Testing for ASTM D638*. https://www.intertek.com/polymers/tensile-testing/astm-d638-iso-527/

Jähn, A., Schröder, M. W., Füting, M., Schenzel, K., & Diepenbrock, W. (2002). Characterization of alkali treated flax fibres by means of FT Raman spectroscopy and environmental scanning electron microscopy. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, *58*(10), 2271–2279. https://doi.org/10.1016/S1386-1425(01)00697-7

Jayamani, E., Loong, T. G., & Bakri, M. K. Bin. (2020). Comparative study of Fourier transform infrared spectroscopy (FTIR) analysis of natural fibres treated with chemical, physical and biological methods. *Polymer Bulletin*, *77*(4), 1605–1629. https://doi.org/10.1007/s00289-019-02824-w

Jogur, G., Nawaz Khan, A., Das, A., Mahajan, P., & Alagirusamy, R. (2018). Impact properties of thermoplastic composites. *Textile Progress*, *50*(3), 109–183. https://doi.org/10.1080/00405167.2018.1563369

John, M. J., Bellmann, C., & Anandjiwala, R. D. (2010). Kenaf-polypropylene composites: Effect of amphiphilic coupling agent on surface properties of fibres and composites. *Carbohydrate Polymers*, *82*(3), 549–554. https://doi.org/10.1016/j.carbpol.2010.05.015

John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers*, *71*(3), 343–364. https://doi.org/10.1016/j.carbpol.2007.05.040

Kabir, M. M., Wang, H., Lau, K. T., & Cardona, F. (2012). Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. *Composites Part B: Engineering*, *43*(7), 2883–2892. https://doi.org/10.1016/j.compositesb.2012.04.053

Kamarudin, S. H., Abdullah, L. C., Aung, M. M., & Ratnam, C. T. (2018). A study of mechanical and morphological properties of PLA based biocomposites prepared with EJO vegetable oil based plasticiser and kenaf fibres. *IOP Conference Series: Materials Science and Engineering*, *368*(1). https://doi.org/10.1088/1757-899X/368/1/012011

Kandola, B. K., Mistik, S. I., Pornwannachai, W., & Anand, S. C. (2018). Natural fibre-reinforced thermoplastic composites from woven-nonwoven textile preforms: Mechanical and fire performance study. *Composites Part B: Engineering*, *153*, 456–464. https://doi.org/10.1016/j.compositesb.2018.09.013

Karim, A. F. A., Ismail, H., & Ariff, Z. M. (2018). Effects of kenaf loading and alkaline treatment on properties of kenaf filled natural rubber latex foam. *Sains Malaysiana*, *47*(9), 2163–2169. https://doi.org/10.17576/jsm-2018-4709-26

KariO. (2011). *How Long Does It Take a Plastic Bottle to Biodegrade? - Postconsumers*. October 31. https://www.postconsumers.com/2011/10/31/how-long-does-it-take-a-plastic-bottle-to-biodegrade/#:~:text=Different kinds of plastic can degrade at different,even take some bottles 1000 years to biodegrade%21%0Ahttps://www.postconsumers.com/2011/10/31/how-lo

Kaza, S., & Yao, L. (2018). At a Glance: A Global Picture of Solid Waste Management. In *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. https://doi.org/10.1596/978-1-4648-1329-0_ch2

Komal, U. K., Lila, M. K., Chaitanya, S., & Singh, I. (2019). Fabrication of Short Fiber Reinforced Polymer Composites. In *Reinforced Polymer Composites: Processing, Characterization and Post Life Cycle Assessment* (pp. 21–36). https://doi.org/10.1002/9783527820979

Koniuszewska, A. G., & Kaczmar, J. W. (2016). Application of polymer based composite materials in transportation. *Progress in Rubber, Plastics and Recycling Technology*, *32*(1), 1–23. https://doi.org/10.1177/147776061603200101

Kumar, P. S. S., & Allamraju, K. V. (2019). A review of natural fiber composites [Jute, Sisal, Kenaf]. *Materials Today: Proceedings*, *18*, 2556–2562. https://doi.org/10.1016/j.matpr.2019.07.113

Latip, N. A., Sofian, A. H., Ali, M. F., Ismail, S. N., & Idris, D. M. N. D. (2019). Structural and morphological studies on alkaline pre-treatment of oil palm empty fruit bunch (OPEFB) fiber for composite production. *Materials Today: Proceedings*, *17*, 1105–1111. https://doi.org/10.1016/j.matpr.2019.06.529

Liu, Y., Zwingmann, B., & Schlaich, M. (2015). Carbon fiber reinforced polymer for cable structures-a review. *Polymers*, *7*(10), 2078–2099. https://doi.org/10.3390/polym7101501

Mahjoub, R., Yatim, J. M., Mohd Sam, A. R., & Raftari, M. (2014). Characteristics of continuous unidirectional kenaf fiber reinforced epoxy composites. *Materials and Design*, *64*(September), 640–649. https://doi.org/10.1016/j.matdes.2014.08.010

Marzuki, N. H., Wahit, M. U., Arsad, A., Othman, N., & Yusoff, N. I. S. M. (2019). The effect of kenaf loading on the mechanical properties of kenaf-reinforced recycled poly(ethylene terephthalate)/ recycled poly(propylene) (rPET/rPP) composite. *Materials Today: Proceedings*, *39*(xxxx), 959–964. https://doi.org/10.1016/j.matpr.2020.04.333

Matmatch. (2020). *Thermoplastics vs. Thermosetting Polymers - Matmatch*. https://matmatch.com/learn/material/thermoplastics-vs-thermosetting-polymers

Mitrus, M., & Mościcki, L. (2011). Thermoplastic Starch. *Extrusion-Cooking Techniques: Applications, Theory and Sustainability*, 177–189. https://doi.org/10.1002/9783527634088.ch14

Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. *International Journal of Polymer Science*, *2015*. https://doi.org/10.1155/2015/243947

Mohanty, A. K., Misra, M., & Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering*, *276–277*, 1–24. https://doi.org/10.1002/(SICI)1439-2054(20000301)276:1<1::AID-MAME1>3.0.CO;2-W

Mohd, H. A. B., Arifin, A., Nasima, J., Hazandy, A. H., & Khalil, A. (2014). Journey of kenaf in Malaysia: A Review. *Scientific Research and Essays*, *9*(11), 458–470. https://doi.org/10.5897/sre12.471

Mutasher, S. A., Poh, A., Than, A. M., & Law, J. (2011). The effect of alkali treatment mechanical properties of kenaf fiber epoxy composite. *Key Engineering Materials*, *471–472*, 191–196. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/KEM.471-472.191

Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. *Journal of Applied Polymer Science*, *84*(12), 2222–2234. https://doi.org/10.1002/app.10460

Navaneethakrishnan, G., Karthikeyan, T., Saravanan, S., Selvam, V., Parkunam, N., Sathishkumar, G., & Jayakrishnan, S. (2020). Structural analysis of natural fiber reinforced polymer matrix composite. *Materials Today: Proceedings*, *21*(xxxx), 7–9. https://doi.org/10.1016/j.matpr.2019.05.295

Netravali, A. N., & Chabba, S. (2003). Composites get greener. *Materials Today*, *6*(4), 22–29. https://doi.org/10.1016/S1369-7021(03)00427-9

Ngaowthong, C., Borůvka, M., Běhálek, L., Lenfel, P., Švec, M., Dangtungee, R., Siengchin, S., Rangappa, S. M., & Parameswaranpillai, J. (2019). Recycling of sisal fiber reinforced polypropylene and polylactic acid composites: Thermo-mechanical properties, morphology, and water absorption behavior. *Waste Management*, *97*, 71–81. https://doi.org/10.1016/j.wasman.2019.07.038

Nimanpure, S., Hashmi, S. A. R., Kumar, R., Bhargaw, H. N., Kumar, R., Nair, P., & Naik, A. (2019). Mechanical, electrical, and thermal analysis of sisal fibril/kenaf fiber hybrid polyester composites. *Polymer Composites*, *40*(2), 664–676. https://doi.org/10.1002/pc.24706

Oladele, I. O., Omotosho, T. F., & Adediran, A. A. (2020). Polymer-Based Composites: An Indispensable Material for Present and Future Applications. *International Journal of Polymer Science, 2020*. https://doi.org/10.1155/2020/8834518

Omnesux. (2017). *Polypropylene (PP) Plastic: Types, Properties, Uses & Structure Info*. Omnexus. https://omnexus.specialchem.com/selection-guide/polypropylene-pp-plastic

Pai, A. R., & Jagtap, R. N. (2015). Surface morphology & mechanical properties of some unique natural fiber reinforced polymer composites-a review. *Journal of Materials and Environmental Science*, *6*(4), 902–917.

Parvej, M. S., Wang, X., Fehrenbach, J., & Ulven, C. A. (2020). Atomic force microscopy-based nanomechanical characterization of kenaf fiber. *Journal of Composite Materials, 54*(15), 2065–2071. https://doi.org/10.1177/0021998319892073

Pilipović, A., Ilinčić, P., Petruša, J., & Domitran, Z. (2020). Influence of polymer composites and memory foam on energy absorption in vehicle application. *Polymers*, *12*(6), 15–20. https://doi.org/10.3390/POLYM12061222

Preda, M., Popa, M.-I., Mihai, M. M., Şerbănescu, A. A., & Holban, A. M. (2019). Natural Fibers in Beverages Packaging. *Trends in Beverage Packaging*, 409–424. https://doi.org/10.1016/b978-0-12-816683-3.00014-1

Rouison, D., Sain, M., & Couturier, M. (2004). Resin transfer molding of natural fiber reinforced composites: Cure simulation. *Composites Science and Technology, 64*(5), 629–644. https://doi.org/10.1016/j.compscitech.2003.06.001

Ryu, J., Kwon, S. J., Ahn, J. W., Jo, Y. D., Kim, S. H., Jeong, S. W., Lee, M. K., Kim, J. B., & Kang, S. Y. (2017). Phytochemicals and antioxidant activity in the kenaf plant (Hibiscus cannabinus L.). *Journal of Plant Biotechnology*, *44*(2), 191–202. https://doi.org/10.5010/JPB.2017.44.2.191

Schecter, A., Colacino, J., Haffner, D., Patel, K., Opel, M., Päpke, O., & Birnbaum, L. (2010). Perfluorinated compounds, polychlorinated biphenyls, and organochlorine pesticide contamination in composite food samples from Dallas, Texas, USA. *Environmental Health Perspectives*, *118*(6), 796–802. https://doi.org/10.1289/ehp.0901347

Sgriccia, N., Hawley, M. C., & Misra, M. (2008). Characterization of natural fiber surfaces and natural fiber composites. *Composites Part A: Applied Science and Manufacturing*, *39*(10), 1632–1637. https://doi.org/10.1016/j.compositesa.2008.07.007

Sherif, G., Chukov, D., Tcherdyntsev, V., & Torokhov, V. (2019). Effect of formation route on the mechanical properties of the polyethersulfone composites reinforced with glass fibers. *Polymers*, *11*(8), 15–17. https://doi.org/10.3390/polym11081364

Sim, Y. Y., & Nyam, K. L. (2019). Effect of different drying methods on the physical properties and antioxidant activities of Hibiscus cannabinus leaves. *Journal of Food Measurement and Characterization*, *13*(2), 1279–1286. https://doi.org/10.1007/s11694-019-00043-5

Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. (2017). Recycling of plastic solid waste: A state of art review and future applications. *Composites Part B: Engineering*, *115*, 409–422. https://doi.org/10.1016/j.compositesb.2016.09.013

Smith, N. (2019). *The Seven Ages of Materials*. Engineering & Technology. https://doi.org/10.1049/et.2019.0900

Song, K. H., & Kim, I. S. (2013). Effects of plasticizer on the mechanical properties of kenaf/starch bio-composites. *Fibers and Polymers*, *14*(12), 2135–2140. https://doi.org/10.1007/S12221-013-2135-7

Srebrenkoska, V., Gaceva, G. B., Avella, M., Errico, M. E., & Gentile, G. (2008). Recycling of polypropylene-based eco-composites. *Polymer International*, *57*(11), 1252–1257.

https://doi.org/10.1002/pi.2470

Taj, S., Munawar, M. A., & Khan, S. (2007). Natural fiber-reinforced polymer composites NATURAL FIBER-REINFORCED POLYMER COMPOSITES. *Pakistan Academy of Sciences*, *January 2007*, 129–144.

Tezara, C., Siregar, J. P., Lim, H. Y., Fauzi, F. A., Yazdi, M. H., Moey, L. K., & Lim, J. W. (2016). Factors that affect the mechanical properties of kenaf fiber reinforced polymer: A review. *Journal of Mechanical Engineering and Sciences*, *10*(2), 2159–2175. https://doi.org/10.15282/jmes.10.2.2016.19.0203

Thakur, V. K., Thakur, M. K., & Gupta, R. K. (2013). Rapid synthesis of graft copolymers from natural cellulose fibers. *Carbohydrate Polymers*, *98*(1), 820–828. https://doi.org/10.1016/j.carbpol.2013.06.072

Venkateshwaran, N., ElayaPerumal, A., Alavudeen, A., & Thiruchitrambalam, M. (2011). Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites. *Materials and Design*, *32*(7), 4017–4021. https://doi.org/10.1016/j.matdes.2011.03.002

Vethaak, A. D., & Leslie, H. A. (2016). Plastic Debris is a Human Health Issue. *Environmental Science and Technology*, *50*(13), 6825–6826. https://doi.org/10.1021/acs.est.6b02569

Wadzani, S. G. (2019). *a Study of Modifications of Filler Dimensions and the Effect of Physical and Mechanical Properties of Pineapple Leaf Fibre Reinforced Polypropylene Composite*.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: Can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, *63*(9), 1259–1264. https://doi.org/10.1016/S0266-3538(03)00096-4

Wang, R.-M., Zheng, S.-R., & Zheng, Y.-P. (2011). Introduction to polymer matrix composites. *Polymer Matrix Composites and Technology*, 1–548. https://doi.org/10.1533/9780857092229.1

Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2013). Plastic degradation and its environmental implications with special reference to poly(ethylene terephthalate). *Polymers*, *5*(1), 1–18. https://doi.org/10.3390/polym5010001

Wisnom, M. R., Gigliotti, M., Ersoy, N., Campbell, M., & Potter, K. D. (2006). Mechanisms generating residual stresses and distortion during manufacture of polymer-matrix composite structures. *Composites Part A: Applied Science and Manufacturing*, *37*(4), 522–529. https://doi.org/10.1016/j.compositesa.2005.05.019

Wnek, G. (2015). *Polymers*. *May 2008*. https://doi.org/10.1081/E-EBBE

Yashas Gowda, T. G., Sanjay, M. R., Subrahmanya Bhat, K., Madhu, P., Senthamaraikannan, P., & Yogesha, B. (2018). Polymer matrix-natural fiber composites: An overview. *Cogent Engineering*, *5*(1). https://doi.org/10.1080/23311916.2018.1446667

Zampaloni, M., Pourboghrat, F., Yankovich, S. A., Rodgers, B. N., Moore, J., Drzal, L. T., Mohanty, A. K., & Misra, M. (2007). Kenaf natural fiber reinforced polypropylene composites: A discussion on manufacturing problems and solutions. *Composites Part A: Applied Science and Manufacturing*, *38*(6), 1569–1580. https://doi.org/10.1016/j.compositesa.2007.01.001

Zare, Y. (2016). Study of nanoparticles aggregation/agglomeration in polymer particulate nanocomposites by mechanical properties. *Composites Part A: Applied Science and Manufacturing*, *84*, 158–164. https://doi.org/10.1016/j.compositesa.2016.01.020

Zhan, J., Li, J., Wang, G., Guan, Y., Zhao, G., Lin, J., Naceur, H., & Coutellier, D. (2021). Review on the performances, foaming and injection molding simulation of natural fiber composites. *Polymer Composites*, *42*(3), 1305–1324. https://doi.org/10.1002/pc.25902

APPENDICES