UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BIODEGRADABLE PACKAGING FROM CASSAVA STARCH AND OIL PALM LEAF: ENVIRONMENT PROPERTIES

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APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology with Honours.

Signature :
Supervisor Name : *Dr. Ridhwan bin Jumaidin*
Date : *10 January 2024*

DEDICATION

Alhamdulillah Praise to Allah for the strength, guidance and knowledge that was given by Allah for me to complete this study.

&

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&

To all people who support me throughout my journey

ABSTRACT

The widespread utilization of traditional food packaging has led to an upsurge in the disposal of non-ecologically friendly packaging waste, which poses problems on the environment. In order to address this issue, numerous environmentally conscious materials have been developed. An eco-friendly biopolymer derived from renewable resources has emerged as a viable substitute for petroleum-based polymers. Starch biopolymer, identified as a biodegradable compound that can be derived from a diverse range of plants, stands out as one of the most abundant renewable, biodegradable, and cost-effective resources currently accessible. Oil palm leaf fiber is a potential fiber that can be employed to reinforce a bio-based polymer composite. Numerous early studies on the characteristics and properties of oil palm leaf have been published; nevertheless, a comprehensive and in-depth examination of this leaf's use as a non-wood packaging replacement is nearly unknown. Hence, the aim of this study is to prepare a biodegradable thermoplastic composed of cassava starch reinforced with oil palm leaf fibre (OPLF), examine its water affinity properties, density, and evaluate its environmental properties. This will enable the production of new materials based on thermoplastic cassava starch reinforced with OPLF. To address the limitations of the cassava starch biopolymer, OPLF were incorporated at varying fiber contents (0%, 5%, 10%, 15%, and 20%). All components, including cassava starch, glycerol, palm wax, and OPLF, were mixed and formed using hot compression molding at a temperature of 155 °C for 60 minutes. The essential properties of the TPCS/OPLF biopolymer composites were assessed to determine their suitability as biodegradable reinforcements. In terms of water affinity, the properties of the OPLF composites were evaluated by moisture content, water absorption and thickness swelling testings. Environment analysis was used to evaluate soil burial and water solubility testings. Additional tests, including Scanning Electron Microscopy (SEM) and density, were conducted to evaluate the performance of TPCS reinforced with OPLF composites. The results showed that increasing oil palm leaf fibre loading from 0 to 20 wt% has led to a drop in moisture content from 10.08% to 5.65%. TPCS matrix showed 40% water uptake and 22.15% swelling whereas TPCS/OPLF composites with 20 wt% loading showed 11% water uptake and 9.54% swelling respectively. Inclusion of 20 wt.% loading had reduced the water solubility of the biocomposites from 38.4% and 30.7%. For the soil burial test, incorporating 20 wt% oil palm leaf fiber decreases the weight reduction for 4 weeks and 8 weeks. Moreover, when fibre loading increases, SEM micrographs of the composite reveal more micro void, crack, and fibre breakage. Overall, the incorporation of OPLF into TPCS has enhanced the functional properties of the composites for short-life product applications.

ABSTRAK

Penggunaan meluas pembungkusan makanan tradisional telah membawa kepada peningkatan dalam pelupusan sisa pembungkusan yang tidak mesra ekologi, yang menimbulkan masalah kepada alam sekitar. Untuk menangani isu ini, banyak bahan yang mementingkan alam sekitar telah dibangunkan. Biopolimer mesra alam yang diperoleh daripada sumber boleh diperbaharui telah muncul sebagai pengganti yang berdaya maju untuk polimer berasaskan petroleum. Biopolimer kanji, yang dikenal pasti sebagai sebatian terbiodegradasi yang boleh diperoleh daripada pelbagai jenis tumbuhan, menonjol sebagai salah satu sumber yang boleh diperbaharui, terbiodegradasi dan kos efektif yang paling banyak boleh diakses pada masa ini. Gentian daun kelapa sawit adalah gentian berpotensi yang boleh digunakan untuk mengukuhkan komposit polimer berasaskan bio. Banyak kajian awal tentang ciri dan sifat daun kelapa sawit telah diterbitkan; namun begitu, pemeriksaan menyeluruh dan mendalam tentang penggunaan daun ini sebagai pengganti pembungkus bukan kayu hampir tidak diketahui. Oleh itu, matlamat kajian ini adalah untuk menyediakan termoplastik terbiodegradasi yang terdiri daripada kanji ubi kayu yang diperkuat dengan gentian daun kelapa sawit (OPLF), mengkaji sifat pertalian air, ketumpatan, dan menilai sifat persekitarannya. Ini akan membolehkan pengeluaran bahan baharu berasaskan kanji ubi kayu termoplastik yang diperkukuh dengan OPLF. Untuk menangani batasan biopolimer kanji ubi kayu, OPLF telah digabungkan pada kandungan gentian yang berbeza-beza (0%, 5%, 10%, 15%, dan 20%). Semua komponen, termasuk kanji ubi kayu, gliserol, lilin sawit, dan OPLF, dicampur dan dibentuk menggunakan acuan mampatan panas pada suhu 155 °C selama 60 minit. Sifat penting komposit biopolimer TPCS/OPLF dinilai untuk menentukan kesesuaiannya sebagai tetulang biodegradasi. Dari segi pertalian air, sifat komposit OPLF dinilai oleh kandungan lembapan, penyerapan air dan ujian pembengkakan ketebalan. Analisis alam sekitar digunakan untuk menilai pengebumian tanah dan ujian keterlarutan air. Ujian tambahan, termasuk Scanning Electron Microscopy (SEM) dan ketumpatan, telah dijalankan untuk menilai prestasi TPCS yang diperkukuh dengan komposit OPLF. Keputusan menunjukkan bahawa peningkatan beban gentian daun kelapa sawit daripada 0 hingga 20% berat telah menyebabkan penurunan kandungan lembapan daripada 10.08% kepada 5.65%. Matriks TPCS menunjukkan 40% pengambilan air dan 22.15% bengkak manakala komposit TPCS/OPLF dengan muatan 20% berat menunjukkan 11% pengambilan air dan 9.54% bengkak masing-masing. Kemasukan pemuatan 20% berat telah mengurangkan keterlarutan air biokomposit daripada 38.4% dan 30.7%. Untuk ujian pengebumian tanah, menggabungkan 20% berat serat daun kelapa sawit mengurangkan pengurangan berat selama 4 minggu dan 8 minggu. Selain itu, apabila pemuatan gentian meningkat, mikrograf SEM komposit mendedahkan lebih banyak kekosongan mikro, retak dan pecah gentian. Secara keseluruhannya, penggabungan OPLF ke dalam TPCS telah meningkatkan sifat fungsi komposit untuk aplikasi produk jangka pendek.

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CHAPTER 1

INTRODUCTION

1.1 Background

The investigation of biodegradable packaging as a replacement for traditional plastic packaging has been encouraged by the growing concern over environmental sustainability. It focuses attention to the idea of biodegradability, the special qualities of starch as a crucial substance, the difficulties presented by plastic waste, and the potential of oil palm leaf fibre as a reinforcing element. The purpose of this study is to raise awareness of the value and potential of biodegradable packaging and its role in reducing environmental problems.

The negative effects of non-biodegradable plastics on the environment have given rise to the need for biodegradable packaging. The capacity of a substance to spontaneously degrade into harmless components through biological processes is referred to as biodegradability (Zeljko, 2017). This property supports a sustainable and circular economy.

According to Teixeira et al. (2009), starch is a complex carbohydrate obtained from a variety of plant sources, is well known for its biodegradability, renewability, and adaptability. Due to its widespread availability, low cost, and distinctive properties, cassava starch in particular has attracted a lot of interest. Cassava starch is a thermoplastic material that can be processed into a variety of shapes, including films and moulded goods, making it appropriate for use in a range of packaging applications. According to Teixeira et al. (2009), the biodegradability of starch-based polymers provides a more environmentally friendly option to traditional plastics and helps to cut down on plastic waste.

An alarming environmental disaster has been caused by the exponential proliferation of plastic packaging. Ecosystems and animals are seriously threatened by conventional plastics since they are not biodegradable and stay for hundreds of years in the environment (Rochman et al., 2013). In addition, the manufacture of plastic releases greenhouse gas emissions and depletes finite fossil fuel reserves (Rochman et al., 2013). By reducing plastic waste and its harmful effects on the environment, biodegradable packaging is an efficient way to allay these worries.

The waste of the palm oil industry known as oil palm leaf fibre shows great potential as a strengthening component for biodegradable packaging. The mechanical properties of packing materials may be improved with the use of this fibrous material because of its high strength, low weight, and biodegradability. The thermoplastic cassava starch composites created by adding oil palm leaf fibre to the mixture offer higher durability, decreased brittleness, and increased biodegradability, further lowering their environmental impact.

An important issue in the world of sustainable packaging is the lack of research on biodegradable containers made of thermoplastic cassava starch and oil palm leaf fibre. The creation of ecologically friendly packaging alternatives will be made possible by conducting thorough investigations and research to examine the possibilities of these materials. By filling this research gap, we can help diverse businesses embrace biodegradable packaging materials and lessen the adverse impacts of plastic waste on the environment.

Hence, biodegradable packaging from thermoplastic cassava starch and oil palm leaf fiber presents a sustainable solution to the pressing issues associated with plastic waste. The combination of cassava starch's biodegradability and thermoplastic properties, along with the mechanical reinforcement provided by oil palm leaf fiber, offers a promising avenue for the development of eco-friendly packaging materials. By embracing biodegradable packaging, we can contribute to reducing plastic waste, conserving resources, and creating a more sustainable future. Further research and development are necessary to optimize the properties and commercial viability of these materials, ensuring their wide-scale adoption in the packaging industry.

1.2 Problem Statement

Biodegradable packaging materials are in greater demand due to the increasing awareness of environmental sustainability. The combination of cassava starch and oil palm leaf fibre carries value as a potential solution in this situation. To completely realise the potential of this biodegradable packaging material, however, a number of challenges must be addressed. The purpose of this paper is to examine the problem statement concerning the limitations of thermoplastic starch (TPS), environmental concerns, and the abundance of oil palm leaf fibre as a renewable resource in the context of developing biodegradable packaging.

Despite its biodegradability and renewable nature, TPS is restricted from widespread use in biodegradable packaging by a number of limitations. The material's susceptibility to absorb moisture is a significant limitation. TPS, which is derived from starch, has a high affinity for molecules of water, resulting in diminished mechanical properties and dimensional instability in humid environments. In addition, TPS has limited heat resistance, limiting its use in applications requiring high-temperature resistance (Khan et al., 2017). These limitations make it difficult to ensure the functionality and durability of TPS-based packaging solutions.

To reduce the environmental impact of conventional packaging, biodegradable packaging materials are being developed. Nevertheless, the production and disposal of biodegradable materials may have unintended environmental effects. Greenhouse gas emissions and potential contamination are of concern due to the use of chemicals and energy-intensive processes in the production of TPS and the disposal of biodegradable packaging in landfills or composting facilities. To address environmental issues comprehensively, it is essential to evaluate the life cycle of biodegradable packaging materials and identify ways to reduce their environmental impact.

The abundant agricultural byproduct of oil palm leaf fibre has significant potential as a reinforcement material for biodegradable packaging. Despite its availability, oil palm leaf fibre utilisation in packaging materials remains limited. Included among the difficulties are fibre extraction, fiber-matrix compatibility, and assuring the uniform distribution of fibres in the packaging matrix. To effectively utilise oil palm leaf fibre as a renewable and sustainable resource, thereby reducing reliance on synthetic materials and contributing to the circular economy, it is essential to overcome these obstacles.

Developing biodegradable packaging from cassava starch and oil palm leaf fibre is a viable way to resolve environmental concerns associated with traditional packaging materials. To assure the functionality and durability of the packaging, it is necessary to surmount the limitations of thermoplastic starch, such as moisture absorption and limited heat resistance. In addition, environmental considerations, such as the life cycle assessment of biodegradable packaging, are essential for minimising unintended environmental effects. Finally, the abundance of oil palm leaf fibre as a renewable resource presents an opportunity for the development of sustainable packaging, but extraction and compatibility challenges must be overcome. By resolving these problem statements, we can contribute to a more sustainable future by advancing the development of biodegradable packaging materials.

1.3 Research Objective

The main objective of this study and research are:

i. To produce biodegradable composite fiber from thermoplastic cassava starch reinforced with oil palm leaf.

ii. To evaluate the water affinity properties and the environmental properties of the biodegradable thermoplastic cassava starch reinforced with Oil Palm Leaf fiber composite.

iii. To produce biodegradable packaging derived from Oil Palm Leaf fiber.

1.4 Significance of study

The justification of this research are as follows:

1. The findings from the study are expected to enhance understanding of the biodegradable thermoplastic cassava starch composites reinforced with oil palm leaf fiber.
2. Regarding waste management, this study has investigated a novel utilization of oil palm leaf wastes as a potential reinforcement for biopolymer composites, presenting a new potential for their application.
3. The development of biodegradable polymer with enhanced properties in this study is expected to aid in addressing the environmental problems regarding the alternative materials for natural fiber-based polymer.

1.5 Scope of Research

This study utilizes cassava starch, oil palm leaf fiber, and glycerol as the main raw materials. The thermoplastic cassava starch mixture is created by combining cassava starch and glycerol in appropriate proportions, with glycerol serving as the plasticizer. Palm wax is added to the mixture of cassava starch and glycerol according to the suitable formulation percentage, acting as a protective agent against water absorption and moisture. The reinforcement, oil palm leaf fiber, is then incorporated into the mixture at the required percentage (0wt%, 10wt%, 20wt%, 30wt% and 40wt%). The fabrication of thermoplastic cassava starch reinforced with oil palm leaf fiber will involve the utilization of a hot press machine. The environmental testing includes water solubility and soil burial tests. Additionally, water affinity testing involves evaluating moisture content, water absorption, thickness swelling, and analyzing the material's morphology using density measurements. Finally, the study concludes by developing biodegradable packaging through hot pressing in a packaging tray mold.

1.6 Structure of thesis

This proposal is organised according to the format supplied by Universiti Teknikal Malaysia Melaka (UTeM), based on this study. This study is divided into four sections: introduction, literature review, methodology and findings. The following are the structure's specifics:

Chapter 1

This chapter describes the purpose of the study in detail and highlights the issue that prompted the investigation. This chapter explained the relevance, objective of this study, problem statement, scope, and nature of the research and work.

Chapter 2

This chapter justifies the total literature review conducted by prior research relevant to this thesis's topic. In addition, this chapter describes the research gaps identified by an assessment of prior studies.

Chapter 3

This chapter described the materials used, materials preparation, testing technique, and data gathering procedures used in this study.

Chapter 4

This chapter explained the environment and water physical hypotheses of the thermoplastic cassava starch reinforced by the oil palm leaf fibre composite. This chapter provided a summary of the testing results and discussion that evaluated.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature on composite materials, natural fibres, oil palm leaf, starch, polymers, the effects of natural fibres on the environment, water affinity characteristics, and other analyses is reviewed in-depth in this section. For the next research and analyses covered in this thesis, a comprehension of these topics is essential. The desire for biodegradable and environmentally friendly packaging materials has gotten more serious as environmental sustainability becomes an increasingly important issue on a worldwide scale. However, there are a number of difficulties in fully using natural fibres for packaging. The challenges include improving fibre processing techniques, maximising compatibility with other biodegradable materials, guaranteeing appropriate barrier qualities, and retaining mechanical strength throughout the course of the product's existence. This study aims to contribute to the advancement of sustainable packaging solutions that fulfill both industry requirements and environmental needs through an examination of the properties, processingtechniques, and performance of composites based on natural fibers. The outcomes of this research will unlock new opportunities for natural fiber-based packaging materials, paving the way towards a more environmentally friendly and sustainable future for the packaging sector.

2.2 Composite

Composites are materials that are formed by the combination of two or more natural or synthetic elements. Composites also known as combination of matrix and reinforcement elements. A matrix is a medium for holding reinforcement together like glue, while reinforcement provide stiffness and strength. When the elements are mixed, a material is produced that has been specifically created for specific function, such as becoming stronger, lighter, or electrically resistant (Maiti et al., 2022).

Composite materials are based on thermoplastic polymers. The matrix prevents the fiber strands from environmental and exterior damage while transferring the load between them. In turn, the reinforcement strengthens the matrix and help it endure fissures and fractures by providing strength and stiffness. Significantly, a combination of elements which composite keep their special physical and chemical properties. Natural fiber-based composites are becoming popular day-by-day and replacing synthetic fiber-oriented composites due to their outstanding biodegradability, renewability, decomposability, stiffness, higher length to weight ratio, and low cost (Hasan et al., 2020). Figure 2.1 shows the classification of composites.

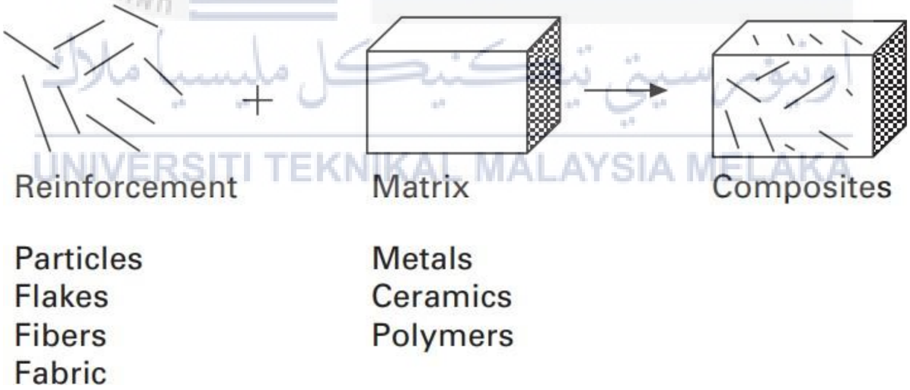


Figure 2.1 formation of a composite material using reinforcement (fibres) and matrix (Wang et al., 2019)

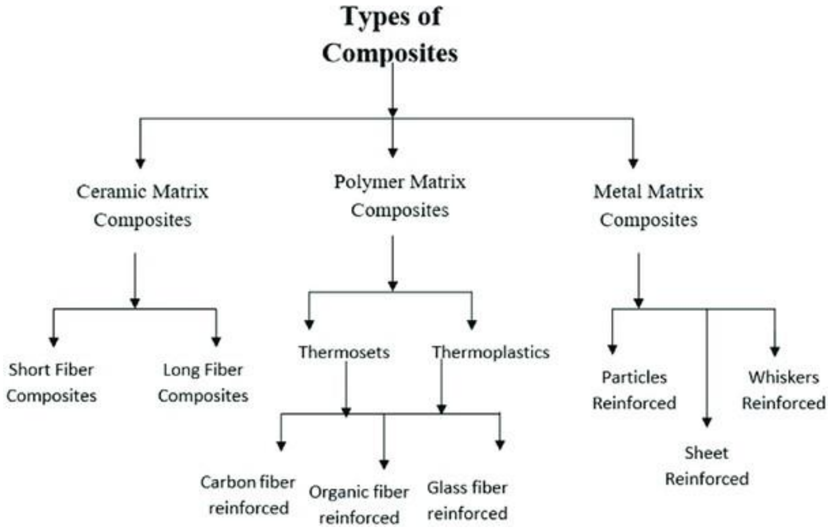


Figure 2.2 Type of composite (Singh et al., 2019)

2.3 Fibre

Composites fiber are made up from two or more different elements which can be organic or inorganic. While the matrix attaches all the fibers together in form and transmits stresses between the reinforcing fibers. Therefore, the fibers are the reinforcement and the primary source of strength (Rabbi et al., 2021). Fiber in a composite, held secure by the matrix resin which provides tensile strength, optimizing final product performance qualities such as strength and stiffness while minimizing weight. Fibres are usually described as thin, long, and flexible thread-like structures. Plants and animals are the two primary producers of fiber. In addition Fiber-reinforced polymer composite offers not only high strength to weight ratio, but also reveals exceptional properties such as high durability, stiffness, damping property, flexural strength, and resistance to corrosion, wear, impact, and fire (Rajak et al., 2019). The two types of fibers shows in Figure 2.3 that can be categorized are natural fiber and synthetic fiber.

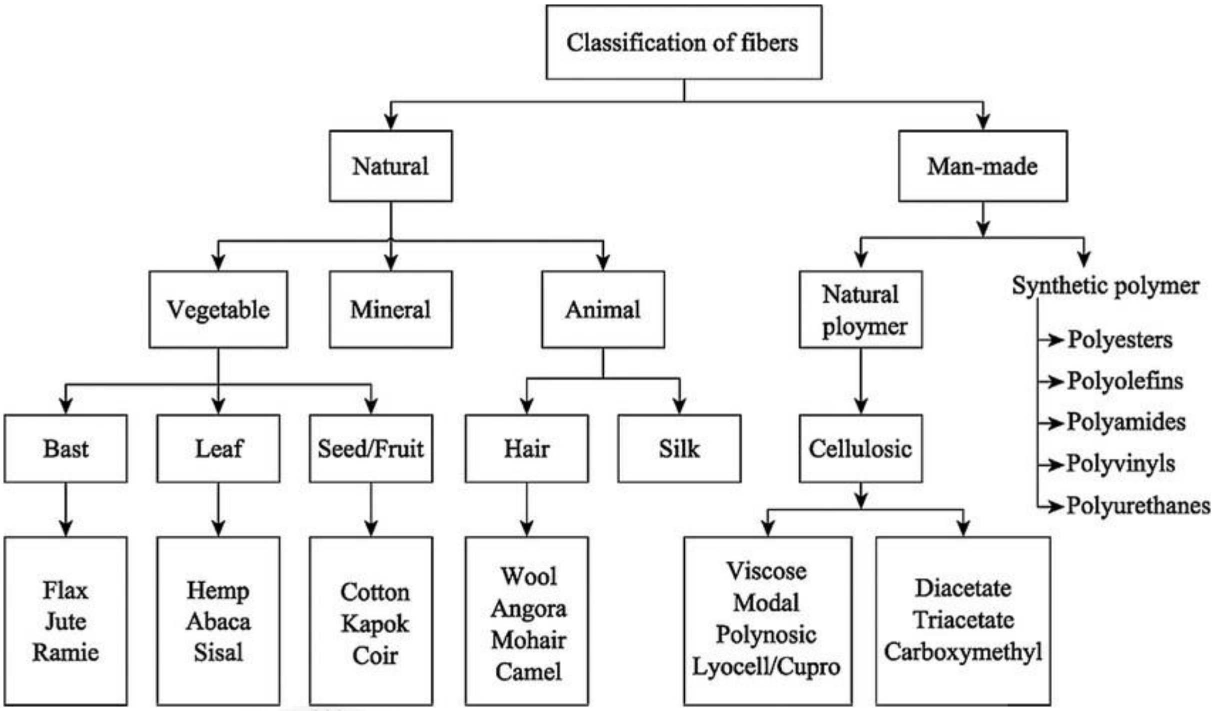


Figure 2.3 Classification of fibres (Xiaoya et al., 2020)

2.3.1 Anatomy of Oil

The oil palm tree, scientifically known as *Elaeis guineensis Jacq.*, is a native plant of West Africa that was introduced to the rest of the world through Portuguese voyages. Prior to its introduction, the oil palm tree was largely unknown outside of Africa (Bakar et al., 2017). It is widely cultivated for its oil-rich fruits, which are used in various industries such as food, cosmetics and biofuel. Here is an overview of the anatomy of an oil palm. Initially, oil palm plantations were planted for the production of vegetable oil, which is thenprocessed into cooking oil and many other products. Despite this, a mere 10% of the biomassis oil-rich (Bakar et al., 2017). Figure 2.4 shows an overview of the anatomy of an oil palm.

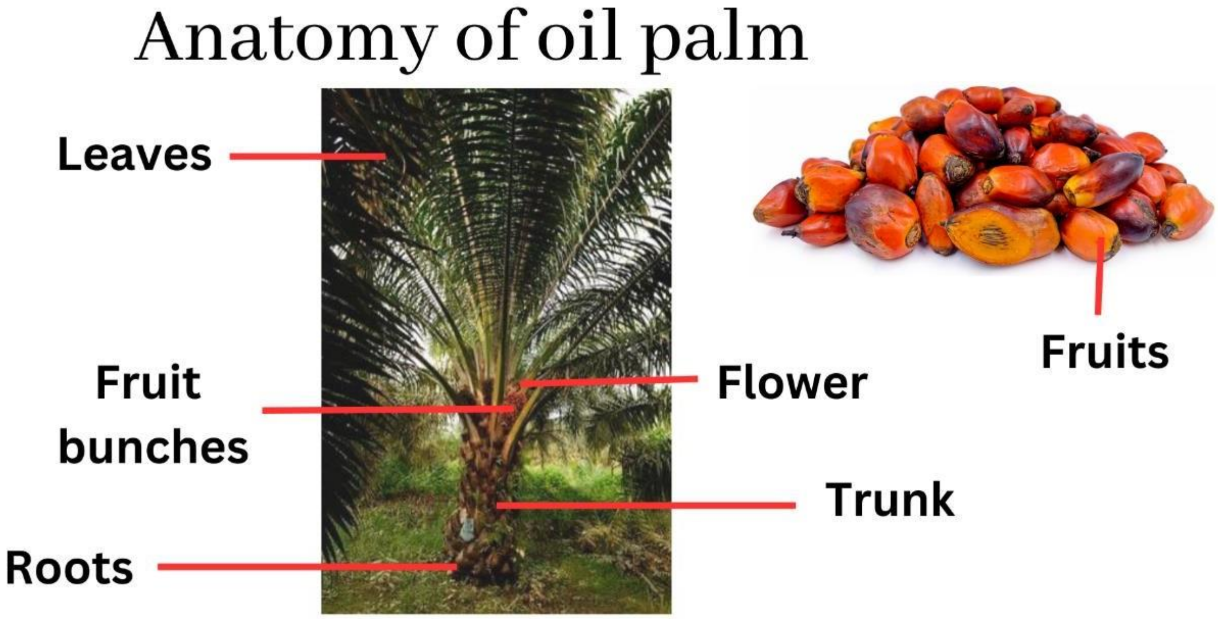


Figure 2.4 Anatomy of an oil palm (Momoh & Osofero, 2020)

The oil palm is a monocot, which means that it has a single, unbranched stem. A palm tree is composed of five main parts, including roots, trunks, fruit bunches, flowers, and leaves. With a fibrous and shallow root system, the oil palm tree primarily develops its roots within the upper 30-60 centimetres of the soil. These roots extensively spread out to efficiently acquire essential nutrients and water from the nearby environment. An oil palm tree has large leaves that can reach a length of more than seven meters. As a result of the leaflets being divided into many sections, the leaves appear feathery.

Oil palm produces clusters of fruits known as bunches, comprising numerous individual fruits. These fruits are approximately plum-sized and exhibit an orange or red hue. Within each fruit, there is a seed encased by a fleshy layer called the mesocarp, which is the part that contains the oil. There are small flowers on the inflorescence of oil palm trees. These flowers are arranged in dense clusters. Generally, the flowers are unisexual, with male and female flowers growing on separate plants (dioecious). Pollen is produced by male flowers, whereas fruit-bearing structures are developed by female flowers.

2.3.2 Characteristic of Oil Palm Fibre

Biocomposites can be made from oil palm fiber (OPF) extracted from empty fruit bunches. Approximately 43%–65% of OPF's cellulose content is cellulose, and 13%–25% is lignin (Shinoj et al., 2011). However, each part of oil palm contain fiber. Empty fruit bunches are the main residue generated by oil milling, fronds are generated from maintenance pruning and replanting, and trunks are obtained only during replanting. The cellulose and hemicellulose in oil palm fibers are held together by lignin, similar to other natural fibers. As a result, they can be categorized as lignocellulosic fibers. Composite fabrication uses oil palm fiber because of its hardness and toughness, as well as its porous surface morphology, which allows for better mechanical interlocking with matrix resin. Hence, oil palm fiber has a high tensile strength, making it suitable for applications that require strong and durable materials.

2.4 Oil Palm Leaf Fibre

The use of natural fibres as reinforcing materials in composite manufacturing has garnered considerable attention due to their renewability, low cost, and environmental benefits. Among the various natural fibres, oil palm leaf fibre (OPLF) stands out as a prospective resource due to its abundant availability as an industrial byproduct (Shinoj et al., 2011). The objective is to emphasise OPLF's sustainable attributes and distinctive qualities, which make it an attractive option for a variety of industries.

Composite materials, which consist of a matrix and reinforcing fibres, have revolutionised a number of industries due to their enhanced mechanical properties, reduced weight, and increased sustainability (Sreekala et al., 1997). As alternatives to synthetic fibres in composite manufacturing, natural fibres like jute, hemp, coir, and sisal have been thoroughly investigated. However, the utilisation of oil palm leaf fibre (OPLF) as a reinforcing material is a relatively recent development that shows great potential. This article investigates the potential of OPLF and its applications in composite materials.

Palm leaf fiber contains the most α-cellulose, and its matrix responds rapidly to chemical surface modifications due to its minimal lignin content. The primary structural component that provides strength and stability to plant cell walls and fiber is cellulose. Fibers with a higher cellulose content are preferred for textile, paper, and other fibrous applications, whereas products with a higher hemicellulose content are more suitable for producing ethanol and other fermentation products, as hemicellulose can be hydrolyzed into fermentable sugars relatively easily. Hemicellulose contributes little to the rigidity and strength of fibres or individual cells and can be hydrolyzed into carbohydrates more readily than cellulose (Kocak & Mistik, 2015). Therefore, fibres with a greater proportion of hemicellulose are preferable for the production of carbohydrates and, ultimately, fuels such as ethanol. Hemicellulose is the most water-absorbent material. High water absorption of natural fibres results in swelling and the presence of cavities, which reduces the mechanical properties and dimensional stability of composites (Kocak & Mistik, 2015).

Oil palm leaf fibre possesses a number of desirable properties that make it an ideal reinforcement material for composites. It has a high tensile strength, a low density, and excellent thermal stability (Shinoj et al., 2011). The fibre is primarily composed of cellulose, hemicellulose, and lignin, which contribute to its mechanical strength and stiffness. The chemical composition and morphology of OPLF impact its compatibility with various matrix materials and, consequently, the performance of the composite (Shinoj et al., 2011).

To use OPLF as a reinforcing material, the fibres must be efficiently extracted from the oil palm fronds. To separate the fibres from the leaf stalks, numerous extraction methods, including mechanical retting, chemical treatments, and microbial retting, have been examined. The choice of extraction method impacts the fibres' quality, purity, and aspect ratio, which in turn affects the mechanical properties of the resulting composites.

Multiple industries can benefit from the incorporation of OPLF into composite materials. These composites have applications in automobile parts, construction materials, packaging, furniture, and consumer goods. OPLF reinforcement can improve mechanical properties, reduce the environmental impact, and offer a sustainable alternative to conventional materials (Kocak & Mistik, 2015).

Despite the extraordinary potential of OPLF as a reinforcing material, there remain obstacles to surmount. Improving fiber-matrix interfacial bonding, optimising extraction methods, and investigating new processing techniques are active areas of research. In addition, the environmental impact of OPLF extraction and its long-term durability in various applications require additional research (Momoh & Osofero, 2020).

2.4.1 Oil Palm Leaf Fibre Composite

Oil palm fiber composite refers to a material made by combining oil palm fibers with a matrix material, typically a polymer, to create a composite material with enhanced properties. Numerous recent studies have been conducted to explore the development of composites using Oil Palm Fiber (OPF) as a filler material. Shinoj et al., (2011) studies aimed to characterize the composites in terms of their mechanical, physical, electrical, thermal, and biodegradation properties. The resulting oil palm fiber composite exhibits a combination of properties from both the fiber and the matrix material. The oil palm fibers provide strength, stiffness, and reinforcement to the composite, while the matrix material helps to bind the fibers together, distribute loads, and protect them from environmental factors. The focus of Shinoj et al., (2011) studies revolved around examining the behavior of these composites under different mechanical loadings such as tensile, flexural, impact, and static, which are crucial in structural and load-bearing applications.

Furthermore, investigations from Sreekala et al., (2001) were carried out to understand stress relaxation and creep behavior in order to predict the long-term mechanical performance of the composites. The dimensional stability of load-bearing structures and the retention of clamping force were also examined. Some studies delved into the crystallization kinetics of specific composites to assess their suitability for high and low temperature applications (Sreekala et al., 2001).

Moreover, the water absorption and swelling behavior of the composites were studied by Abdul Khalil & Ismail, (2000) to evaluate their potential applications in packaging, the building industry, wastewater treatment, and other related areas. The electrical properties of the composites were explored for potential use in electrical insulators, electronic components, and other electrical applications.

Another important aspect addressed in research was the biodegradation of OPF composites. Understanding their resistance to fungal attack is essential for outdoor usage and for facilitating composting at the end of their life cycle, rather than resorting to burning (Khalil and Ismail, 2001).

The properties of the composite primarily rely on the characteristics of the matrix, which leads to the selection of a suitable matrix based on the desired end properties of the composite (Kocak & Mistik, 2015). When considering a specific combination of matrix and fiber, various parameters such as fiber content, orientation, size, and treatments play a significant role in influencing the bonding between the fiber and matrix, as well as the final properties of the composite (Shinoj et al., 2011). Oil palm fiber has been experimented with in a range of matrices, including natural rubber (NR), polypropylene (PP), polyvinyl chloride (PVC), phenol formaldehyde (PF), polyurethane (PU), epoxy, polyester (Shinoj et al., 2011).

2.5 Palm wax

Palm wax is a derivative of palm oil extracted from the fruit of Elaeis guineensis, a prominent crop in Malaysia, Indonesia, and Thailand (Keng et al., 2009). The composition of palm wax is primarily comprised of long-chain saturated fatty acids, particularly palmitic acid (C16:0) and oleic acid (C18:1), which contribute to its notable hydrophobic properties. Compared to other waxes such as carnauba wax, candelilla wax, and beeswax, palm wax exhibits a lower melting point ranging from 58 to 60°C (Arcan & Yemenicioğlu, 2013). This characteristic renders it suitable for incorporating thermosensitive active compounds, including phenols or terpenoids, that necessitate lower processing temperatures. Additionally, due to the substantial presence of saturated compounds within its chemical composition, palm wax displays enhanced resistance to traditional autooxidation, which typically targets double bonds (Garrison & Dayan, 2011). Consequently, palm wax exhibits a prolonged oxidative stability, making it a viable option for applications requiring long-term stability.

According to Syahida et al., (2020), as a possible affordable and ecologically friendly alternative to hydrophobic chemicals generated from fossil sources, palm wax has recently come to light. Although often used in the production of candles, its technical uses are still few, especially in the food business. Therefore, this study sought to explore its impacts on the physical, microstructural, and water barrier characteristics of gelatin-based films in order to assess the possible use of palm wax in the production of packaging materials. A thorough evaluation of palm wax's suitability as a component in packaging materials may be established by examining these essential properties, therefore extending its applicability beyond its existing restrictions.

2.6 Starch

Starch is considered to be one of the most promising natural polymers because of its biodegradability, abundance, and renewability on an annual basis. Its low cost and it can be processed with conventional plastic processing equipment make it an attractive base for creating new biodegradable polymers. This has made it a popular choice for use in low-cost applications (Jiang et al., 2020). Starch is one of the most important polymers that has been extensively used daily in both food and non-food application. According to Thakur et al., (2019), starch is a type of polymeric carbohydrate that consists of linked 1,4-linked D-glucose units. It can be subdivided into two main forms, amylose and amylopectin, which make up almost all of the dry mass of starch. These components are arranged in concentric rings that form semi-crystalline and amorphous layers (Thakur et al., 2019).

Starch is comprised of small granules that are influenced by their botanical origin, resulting in variations in granule size, morphology, shape, and size distribution. These factors affect the properties of the starch. Starch granules come in different sizes, and this is influenced by their plant source. They can be as small as less than 1 µm or as large as over 100 µm in diameter. Smaller granules are more favorable for enzymatic hydrolysis because they provide a larger surface area for enzymatic binding and reaction. Starch is a type of polymer made up of linked glucose units, which form inert granules within the chloroplast. Fig 2.6 shows the chemical and physical structures represent amylose and amylopectin starches. In leaves, transitory starch is produced during the day from photosynthetic assimilates and then broken down at night to provide energy for growth (Pokhrel, 2015).

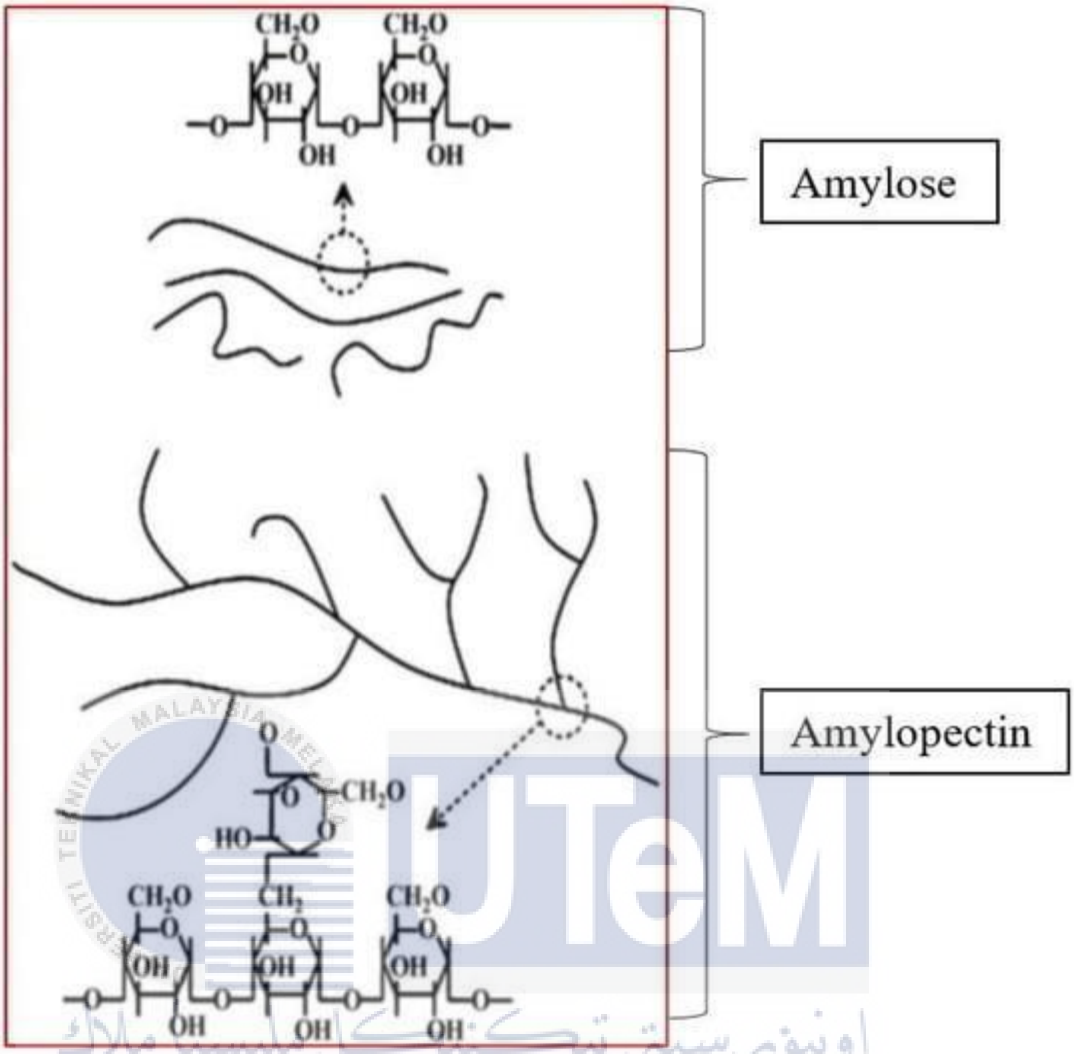


Figure 2.5 Chemical structures and physical schematic representation of amylose starch and amylopectin starch (Rostamzad, 2020)

According to Jiang et al., (2020)'s study, starch consist two microstructure which linear and branched. The amylose structure is linear and consists of α-1,4 linked glucose units, while the amylopectin structure is highly branched and composed of short α-1,4 chains linked by α-1,6 bonds. Fig 2.6 shows the chemical and physical structures represent amylose and amylopectin starches. Amylose has a molecular weight of approximately 10^6, which is ten times higher than that of synthetic polymers like PE, PP, and PS. On the other hand, amylopectin has an even higher molecular weight compared to amylose (Jiang et al., 2020).

2.6.1 Application of Starch

Starch, being the most abundant carbohydrate stored in plants, plays a crucial role in determining the quality of food products. Starch is a crucial energy source in human diets and its versatility in a wide range of food products makes it more popular than other carbohydrate polymers. As a result, starch is receiving significant attention. Starch has various uses in different industries. It can be utilized as a thickener, binder, and stabilizer in the food industry. It is also employed in the production of paper, textiles, and adhesives, and in the pharmaceutical industry, it acts as a filler and binder for tablet formulations. Moreover, due to its biodegradable and renewable nature, starch shows promise as a material for sustainable use in various industrial applications (Pokhrel, 2015).

2.6.2 Thermoplastic starch

Thermoplastic starch (TPS) is a biodegradable and renewable polymer that is produced by plasticizing native starch, chemically or physically modifying it, or merging it with other polymers to improve its thermoplasticity and processability. The production of thermoplastic starch requires the addition of plasticizers such as water, glycerin, sorbitol, and glycol. By employing high temperature and shearing operations, the material becomes readily molten and moldable, making it suitable for injection, extrusion, and blast moulding, among other processes. Thermoplastic starch can be produced from a variety of starch sources, including corn starch, potato starch, wheat starch, and maize starch. The creation and refining of thermoplastic starch are regarded as crucial for reducing the global accumulation of synthetic plastic waste. Thermoplastic starch (TPS) is produced by exposing starch granules to low water content, high temperature, and shear force in the presence of thermostable plasticizers. This process alters the granule's structure, resulting in the formation of TPS (Pokhrel, 2015).

TPS has prospective applications in packaging, agriculture, medicine, and other industries as a renewable and environmentally benign alternative to polymers derived from petroleum. Although native starch lacks thermoplastic properties, it can manifest them when combined with plasticizers, subjected to thermal processes, and under shear stress (Ma et al., 2005). This altered form of starch is known as thermoplastic starch (TPS), and it can be shaped into a variety of products, including films and moulded objects. The characteristics of TPS products, such as tensile strength, elongation at break, elastic modulus, gas barrier, and glass transition, are significantly affected by variables such as plasticizer concentration, moisture content, and processing parameters (Zhang et al., 2013).

2.6.3 Thermoplastic Cassava Starch

Cassava, also known as *Manihot esculenta Cranz*, *Manioc*, Tapioca, or Ubi Kayu, holds the distinction of being the fifth most extensively cultivated starch crop globally (Edhirej et al., 2017). Cassava has low nutritional content and possesses elevated levels of cyanogenic glycosides. When the cassava is damaged, these compounds break down and release toxic hydrogen cyanide (Gleadow et al., 2009). Thermoplastic cassava starch refers to a modified form of cassava starch that exhibits thermoplastic properties. It is produced by treating cassava starch with specific additives and processing techniques, which enable it to melt, flow, and be shaped when exposed to heat.

Cassava, as a versatile ingredient, possesses various essential functional characteristics that significantly contribute to its overall high quality. One of these characteristics is the granule characteristic, which refers to the physical structure of the cassava starch granules. The size and shape of the granules can influence the rate at which they absorb water and swell, impacting the texture and consistency of the end product. For instance, granules with a larger size may have slower hydration rates and less swelling capacity compared to smaller granules (Sriroth et al., 1999). The utilization of cassava starch is extensive due to its exceptional ability to thicken, its affordability, high purity, and its capability to form clear and viscous pastes. However, cassava starch faces limitations such as having a single functionality and low added value in various industries. To address these challenges and broaden its applications, chemical and physical modifications are commonly employed (Gleadow et al., 2009).

Chotiprayon et al., (2020) conducted research on the thermoplastic properties of cassava starch blend reinforced with coir fiber. The coir fiber (CF) used in this study were from coconut waste. As a by-product of coconut products such as coconut milk, coconut oil, and coconut water, coir fibre is an overabundance of fibre. Among natural plant fibres, CF is lightweight (density of 1.15–1.5 g/mL), highly flexible (elongation at failure of 15–51.4%), and inexpensive ($0.30–0.50/kg) (Yan et al., 2016).

The chemical composition of empty fruit bunches fibre and oil palm fronds is summarized in Table 2.2. Internal mixing and shaping of thermoplastic cassava starch and glycerol as plasticizer were accomplished using a compression moulding machine.

Table 2.1 Chemical composition of empty fruit bunches (EFB) and oil palm fronds (OPF)

Composition (%)	Empty fruit bunches (EFB)	Oil palm Fronds (OPF)
Cellulose	**30-50%**	**49.8%**
Lignin	**20–30%**	**20.5%**
hemicellulose	**15–35%**	**83.5%**

The description of a previous report on thermoplastic cassava starch composites is shown in Table 2.3. It is concluded that thermoplastic derived from cassava has promising properties as a biopolymer matrix compatible with most natural reinforcement materials as well as thermoplastics derived from cassava. Additionally, cassava-based thermoplastics have great potential as an environmentally friendly packaging material.

Table 2.2 Thermoplastic cassava starch composites

TYPE OF STARCH	TYPE OF FILLER/POLYMER	POTENTIAL APPLICATION	REFERENCES
Cassava	Jute, Kapok	Packaging	(Prachayawarakorn et al., 2013)
Cassava	Cassava bagasse	Packaging	(Teixeira et al., 2012)
Cassava	Banana leaf fibre	Packaging	(Sivakumar et al., 2022)
Cassava	Carrageenan, Cotton fibre	Biodegradable material	(Prachayawarakorn & Pomdage, 2014)

2.6.4 Application of Thermoplastic Starch

Thermoplastic starch, which is derived from various sources of plants including cassava, corn, and potato, provides a biodegradable and renewable alternative to the traditional petroleum-based plastics that have been used for centuries. Several industries have found applications for it, and it has gained a lot of attention. Thermoplastic starch polymer has a number of applications such shopping bag, food packaging, cutlery and etc. Thermoplastic starch has emerged as an environmentally friendly alternative to conventional petroleum-based plastics. As a result of its unique properties, it is well suited for the production of a variety of packaging materials. Example of thermoplastic starch packaging indicates in Figure 2.7.

Thermoplastic starch films, trays, and containers offer several advantages in terms of barrier properties, strength, and flexibility. The packaging materials protect the contents from external factors such as moisture, gases, and contaminants, which ensures the freshness and quality of the packaged goods. Additional additives or coatings can enhance the barrier properties of thermoplastic starch films in order to meet specific packaging requirements.

Figure 2.6 Example of thermoplastic starch food packaging (Halley & Dorgan, 2011)

According to Bangar et al., (2021), considering the environmental contaminants, health concerns, and disposal issues that come with food packaging, it may be worthwhile to consider the use of biodegradable polymer derived from starch as an effective alternative. Since starch is an environmentally friendly, sustainable, and inexpensive biopolymer, which could feature as a promising method of producing biocomposite materials.

Biodegradable polymers are important in plastic engineering because they can be used as an alternative to petroleum-based polymers that are non-degradable, non-renewable and cannot be degraded. A mixture of starch and poly (lactic acid) could be used to manufacture tooth brush handles, flower pots and cups by blending the two materials. Considering that industrial chemistry is undergoing an environmental transformation, starch-based biodegradables become more valuable in light of this trend. Thus, biodegradable polymers are gaining attention from researchers as a result of this development. Considering the environmental benefits associated with utilizing renewable resources as feedstocks, it is clear that the market for biodegradable polymers will continue to grow in the coming years, contributing to a promising future for the industry.

2.7 Effect of Natural Fibre on Environment Properties of Thermoplastic Starch

2.7.1 Moisture Content

The moisture content, known as natural moisture content, is the ratio of the weight of water to the weight of the solids in a given mass of soil. Jumaidin et al., (2019) stated that combination of sugarcanes fiber with thermoplastic potato starch (TPPS) will decrease the moisture content. These composites were developed by using dry mixing and hot press method at 145°C for 1 hour by maintaining the composition of starch and glycerol. The study shows more sugarcane fiber added; hence moisture content will decrease. According to Figure 2.8, the sugarcane fiber content will affect the moisture content. As the fibers were added to the biocomposite, the moisture content decreased, leading to improved interfacial bonding between the matrix and fibers due to increased resistance to moisture absorption (Adam, Jumaidin, Ridhwan et al., 2019).

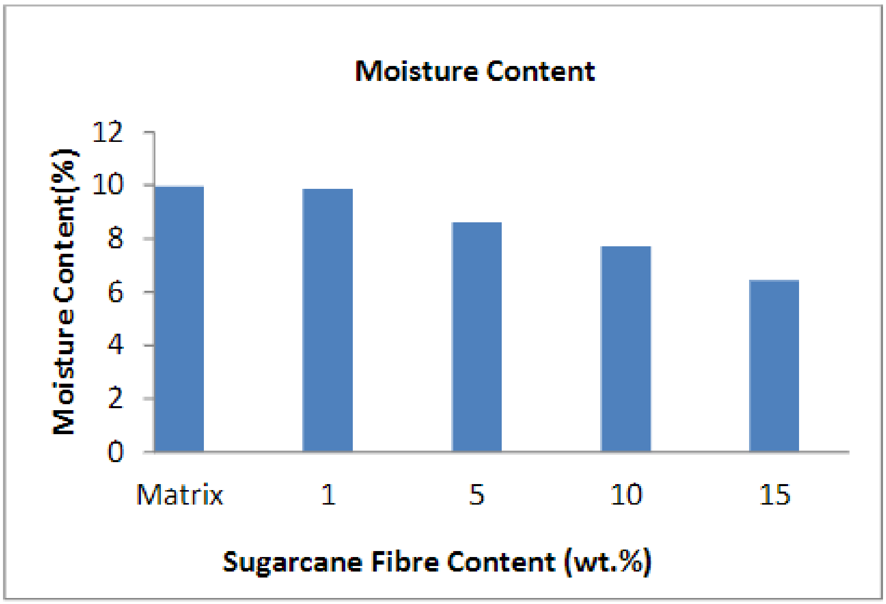


Figure 2.7 Moisture Content for TPPS/sugarcane bagasse composites (Adam, Jumaidin et al., 2019)

Kamaruddin et al., (2023) investigated the effect of Cymbopogan citratus fibre on thermoplastic cassava starch/palm wax composites' moisture content. The moisture content of the thermoplastic starch/palm wax composite without fibre have higher amount of moisture content which might be due to the strong hydrogen interactions between the hydroxyl groups in starch and the free water molecules. However, the increase in CCF content from 10 to 60 wt.% resulted in a slight reduction in the moisture content of the TPCS/PW/CCF samples which similar result with jumaidin et al., (2019).

2.7.2 Water Absorption

Water absorption refers to the process by which a substance, such as a solid or a fabric, takes in or absorbs water molecules. The absorption of water can occur through various mechanisms, depending on the nature of the material involved. Polypropylene (PP) known as good moisture resistance which PP has low water absorption and is inherently moisture resistant, which makes it suitable for outdoor applications or products exposed to humid environments It remains its mechanical properties even in moist environments. The water absorption behaviour of Luffa Fibre composites reinforced with thermoplastic starch was investigated in a study conducted by Kaewtatip & Thongmee, (2012).

The results revealed that the water absorption of TPS/luffa fibre composites decreased with increasing fibre content. Specifically, as the luffa fibre content increased from 5% to 20%, water absorption was observed to decrease significantly. This decrease in water absorption is due to the hydrophilic nature of starch in comparison to cellulose, as well as the presence of fibre, which decreases hydrophilicity.

In addition, the strong adhesion between the TPS and luffa fibre is essential in limiting the free volume of the starch molecular chains, thereby preventing water penetration. The increased interaction between the TPS matrix and luffa fibre strengthens the composite structure and limits the movement of water molecules within the material. As a result, the water absorption capability of the TPS/luffa fiber composites is effectively reduced. These findings highlight the significant influence of fiber content and adhesion on the water absorption behavior of the composite materials. Figure 2.9 shows the decrease water absorption with increase Luffa fibre content.

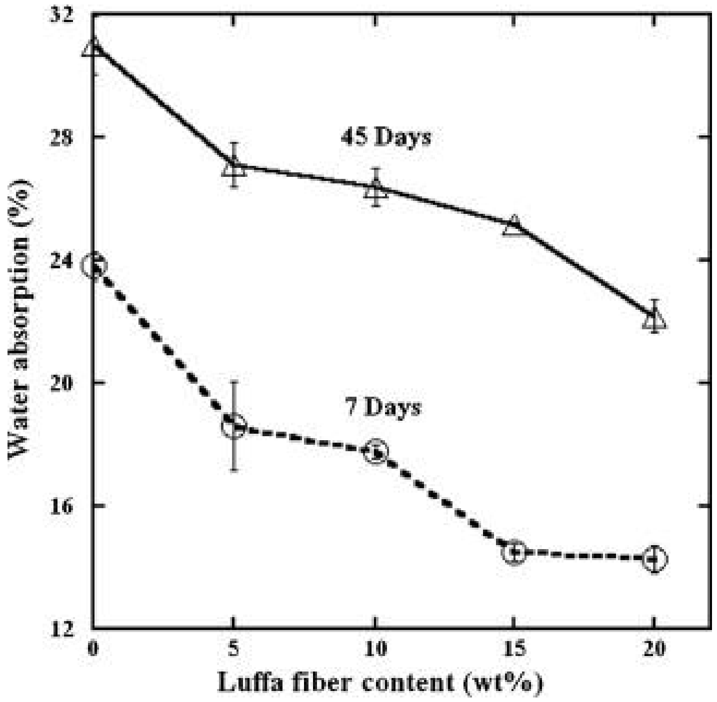


Figure 2.8 Water absorption with Luffa Fibre content (wt%) (Kaewtatip & Thongmee, 2012)

According to Jumaidin et al., (2019), thermoplastic starch is sensitive to water. This study used sugarcane fiber reinforce thermoplastic potato starch (TPPS). It shows the water absorption capacity of the TPPS matrix and its composites after immersion for 0.5 hour. The result of this study, by adding different amount of sugarcane fiber into TPPS will decrease amount of water absorption. It is due to the good interfacial bonding between fibre and matrix, higher affinity of the matrix for water compared to fibres induces and the linkage formed by the higher fibre content which restrain the absorption of water through the starch-matrix. Figure 2.10 shows the higher amount of fiber added, the lower water content in it.

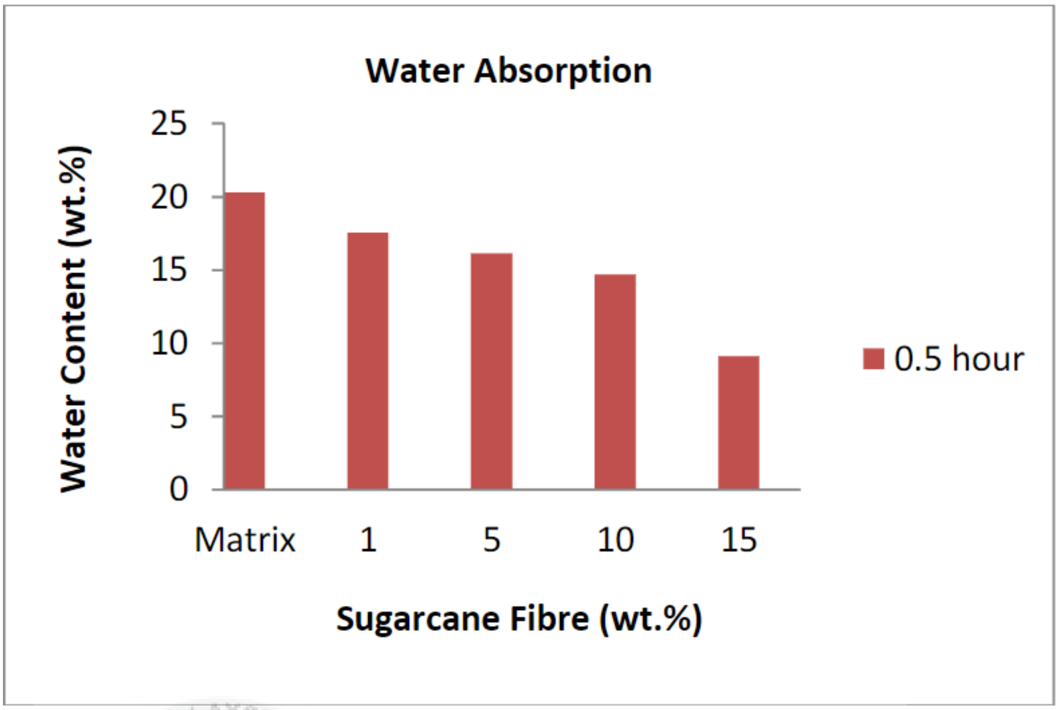


Figure 2.9 Water Absorption of TPPS/sugarcane composites (Jumaidin et al., 2019)

2.7.3 Thickness Swelling

Thickness swelling (TS) is composed of two different factors, water immersion performance and dimensional changes resulting from changes in relative humidity from 10 to 90%. The dimensional stability of a material can be assessed by measuring the extent to which it swells or contracts due to moisture movement within the material. Jumaidin et al., (2022) incorporated TPCS/Beeswax with cogon grass fiber to check the thickness swelling. Figure 2.11 shows the swelling percentage of TPCS/Beeswax and the composites with different percent of fiber (0% -40% wt). This study proof that the immersion time and fibers load influenced the thickness of matrix and composites. This is the result, TPCS/Beeswax with 30 wt.% shows the highest swelling after 0.5 hour of immersion time, while 40 % amount of cogon grass fiber shows the highest swelling after 2-hour immersion time.

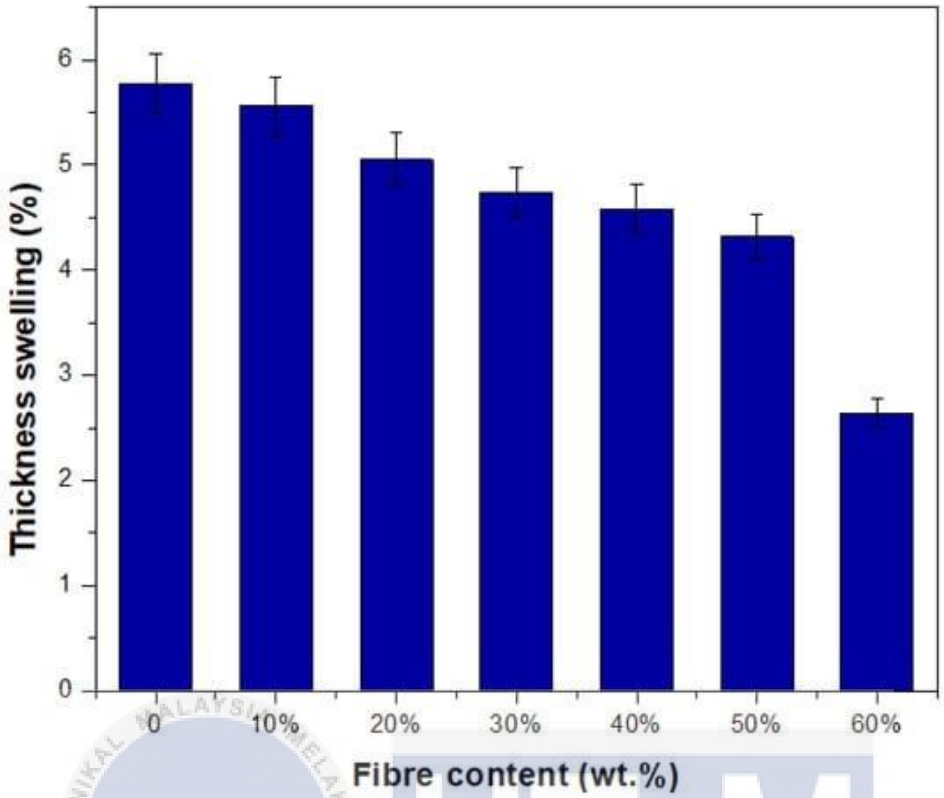


Figure 2.10 Thickness swelling of cogon grass fibre (Jumaidin et al., 2022)

This finding was also confirmed by Kamaruddin et al., (2023) who found out about thickness of all samples decreased gradually with increasing fibre content. It can beattributed to the presence of fibre in the composites, which possesses a more rigid structurethan starch, providing higher dimensional stability to the composites. In this research, the addition of sugar palm fibre reduced the sample's swelling and affected the way the polymerchains interacted, which may have a negative impact on the polymer's capacity to swell. Each sample's swelling behaviour decreased when the fibre content was increased (Kamaruddin et al., 2023).

2.7.4 Water Solubility

The water solubility of samples is a critical property that deserves consideration in various applications. For applications where moisture and water loss protection are necessary, it is important to ensure low water solubility. Figure shows the TPCS/PW/CCF biocomposites’ water solubility. Kamaruddin et al., (2023) studied the water solubility shows the effect of water immersion and constant stirring by composites samples. This study prepared thermoplastic cassava starch/palm wax blends incorporated with Cymbopogan citratus fibre (TCPS/PW/CCF) bio-composites at different CCF concentrations of 0, 10, 20, 30, 40, 50 and 60 wt%. The result these study shows little decrement in biocomposites solubility. The higher fibre content added, the lowest water solubility for biocomposites (Kamaruddin et al., 2023). Figure 2.12, presents water solubility of TPCS reinforced with Cymbopogan citratus fibre from 0 to 60 wt.% fibre contents.

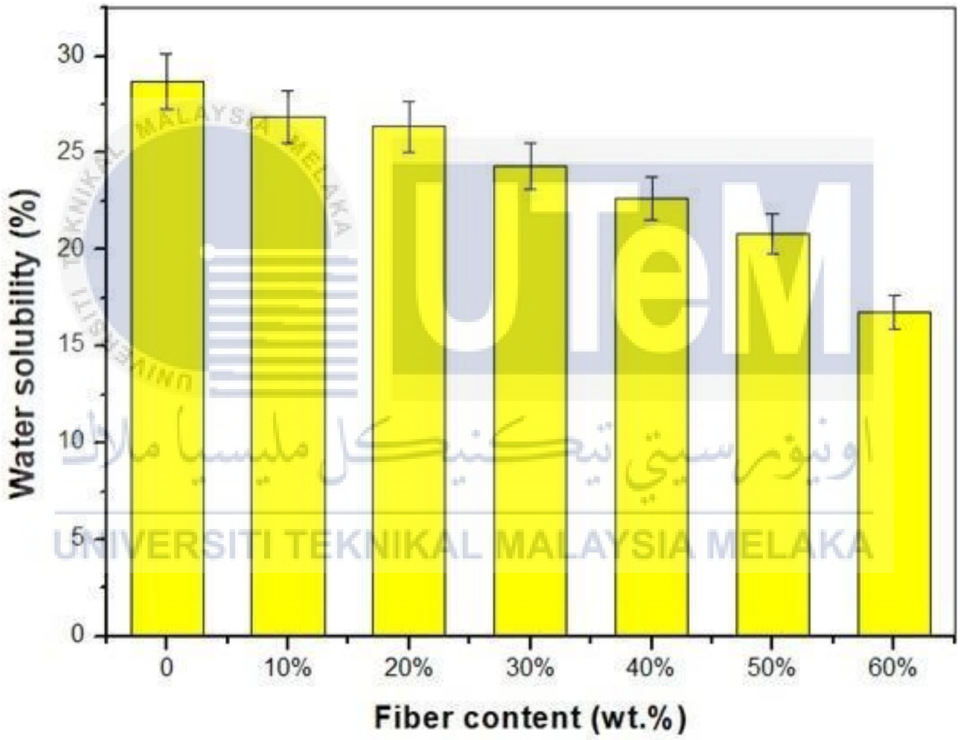


Figure 2.11 Water Solubility of TPCS/PW/CCF biocomposites (Kamaruddin et al., 2023)

The water solubility properties of thermoplastic cassava starch (TPCS) composites including palm wax at various loadings were reviewed and analysed by Hafila et al. in 2022. Figure 2.13 shows that the water resistance of the TPCS matrix significantly increased when palm wax was added, as seen by a drop in solubility from 33.82% to 23.39%. This improvement can be due to palm wax's hydrophobic properties and how it interacts with starch to generate a dense network that prevents water molecules from accessing hydroxyl groups. As a result, the bio composites' hydroscopic properties are reduced. It was found that the TPCS/palm wax composites' water solubility reduced more when the palm wax concentration was increased.

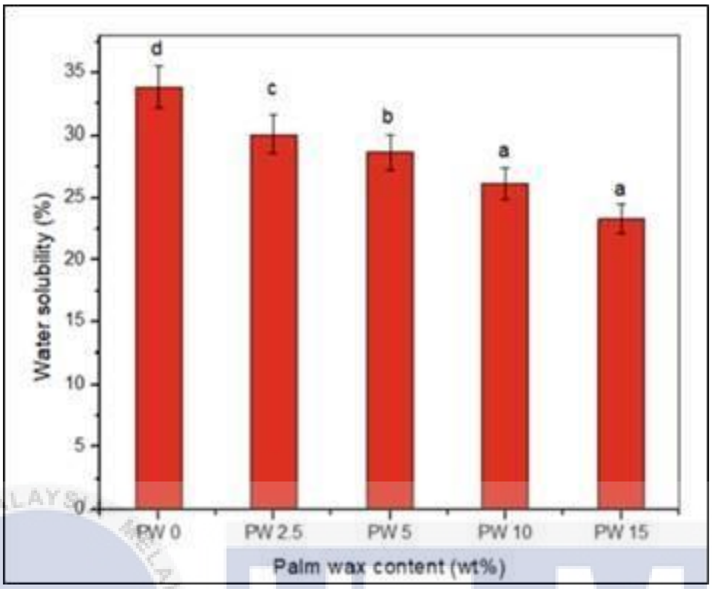


Figure 2.12 Water solubility of TPCS with different amount of palm wax content (Hafila et al., 2022)

Due to the fact that palm wax is water insoluble, it helps develop hydrophobic interactions, which decreases the number of binding sites that are available. In research using palm wax in various bio composite systems, similar outcomes have been found. Notably, palm wax retains the structural integrity of the composites when submerged in water while also enhancing water resistance. These results show the potential of palm wax as a powerful addition for improving water resistance and maintaining the integrity of bio composites based on TPCS.

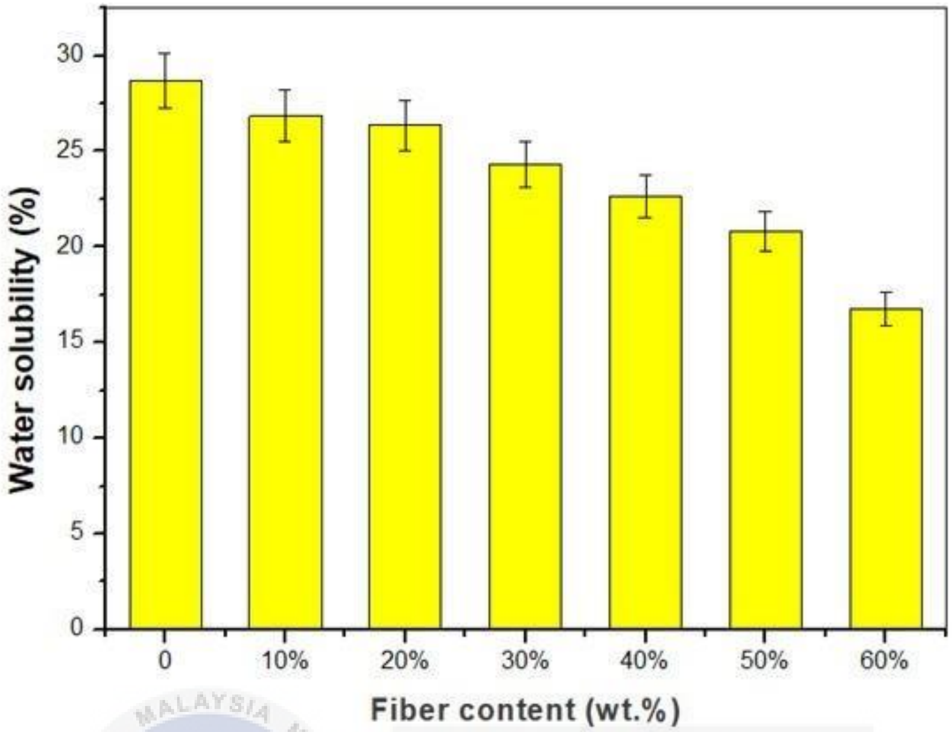


Figure 2.13 Water Solubility of TPCS/PW/CCF biocomposites (Kamaruddin et al., 2022)

2.7.5 Soil Burial

The material weight loss can be used to determine the rate of biodegradation by moisture and microorganisms throughout the soil burial period. Kamaruddin et al., (2022) studied the influence of soil burial that affect fiber combine with TPCS in biodegradation of composites. This study used *Cymbopogan citratus fibre* (CCF) were incorporated into thermoplastic cassava starch (TPCS) with various content of CCF (10, 20, 30, 40, 50, 60 wt.%) via compression moulding. The author weight the loss percentage of thermoplastic cassava starch with the CCF addition after two and four weeks of soil burial is shown in Figure 2.15 . After a duration of 4 weeks of burial, the composites demonstrated higher weight losses compared to those observed after 2 weeks.

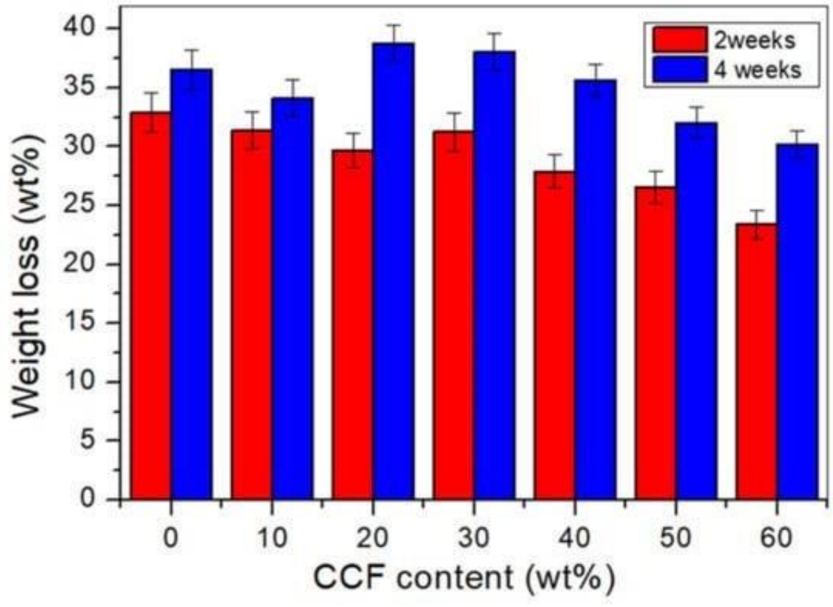


Figure 2.14 Weight loss of TPCS/CCF composites after soil burial for 2 and 4 weeks (Kamaruddin et al., 2022)

This outcome can be attributed to an increased level of microorganism activity during the extended burial period, thereby amplifying the material's weight loss. The addition of Cymbopogan citratus fibre into the TPCS matrix resulted in a smaller weight percentage change than the TPCS matrix. Consequently, the lower weight loss observed in TPCS/Cymbopogan citratus fiber composites can be attributed to the higher resistance to biodegradation of CCF, which is a result of the materials' reduced hydrophilicity.

This finding was also confirmed by Nazri et al. (2020), who found that an increase in fibre content will reduce weight loss. This research combines thermoplastic corn starch (TPCS) and pineapple leaf fibre (PALF). At a temperature of 165 °C for 15 minutes, the technique of hot compression moulding was used to produce samples of TPCS with varying weight percentages of PALF. This study demonstrates that increasing the PALF content of a composite reduces weight loss. As a result of the low hygroscopic properties, fewer microorganisms may be present.

2.7.6 Density

A material's density has a significant impact on its compressive strength and elasticity modulus. Thermoplastic cassava starch (TPCS), palm wax (PW), and coconut coir fibre (CCF) were studied in biocomposites in a recent study by Kamaruddin et al. (2023), with CCF loading ranging from 0% to 60% of the fibre content. The TPCS/PW/CCF biocomposite revealed a minor but noticeable variation in density.

It's important to note that the density of the biocomposite decreased as the fibre loading increased, as seen in the Figure 2.16. This finding suggests that as CCF is added, the mass proportion of the biocomposite decreases, which explains the declining trend in density. As the percentage of the TPCS/PW matrix decreases while the volume remains constant, the introduction of fiber leads to a decrease in the overall mass of the biocomposite.

Consequently, the decrease in biocomposite mass has an effect on the density values of the samples. Notably, the increase in filler content, in this instance CCF, may contribute to the lower density due to the filler material's lighter density (Kamaruddin et al., 2023). This finding emphasises the significance of contemplating the influence of infill materials on the density of biocomposites and offers insight into optimising the density properties of such materials for a variety of applications.

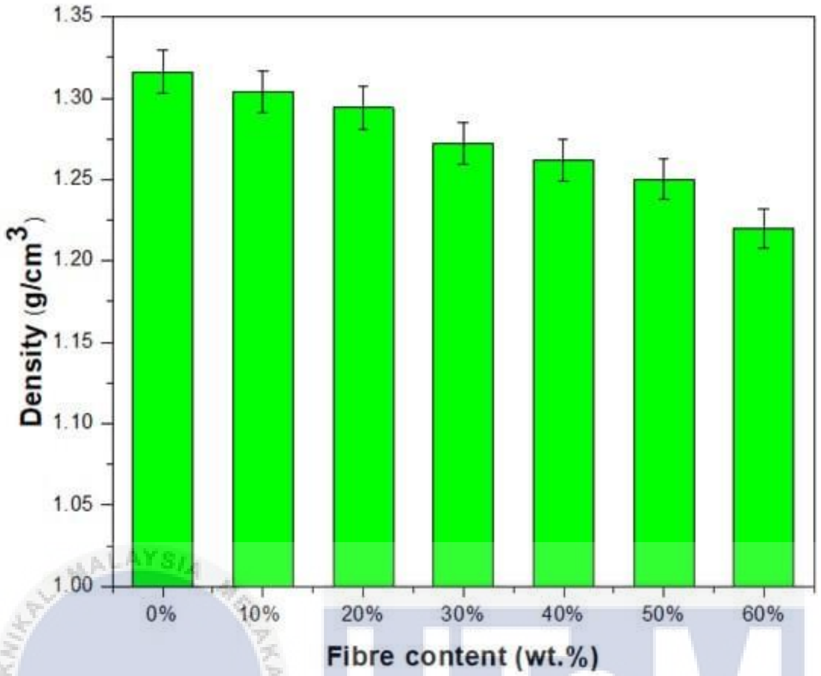


Figure 2.15 Density of fiber content (Kamaruddin et al., 2023)

In a study conducted by Nazri et al. (2020), focused on Thermoplastic Corn Starch (TPCS) reinforced with Pineapple Leaf Fiber (PALF) composites. The density results exhibited a slight decrease with increasing PALF content, reaching the lowest value of 1.23 g/cm³ at a fiber loading of 60 wt.%. It was observed that the highest density was achieved at a fiber loading of 20 wt.%, measuring approximately 1.32 g/cm³. Interestingly, The observed decrease can be attributed to the spilling of the matrix from the mold caused by the application of pressure and heat during the manufacturing process.

The density test results can also be explained by the interfacial bonding between the matrix and the fiber. Poor interfacial bonding leads to a higher density value as it prevents effective integration between the two components. The influence of interfacial bonding on density highlights the importance of achieving a strong bond between the matrix and fiber to optimize the physical properties of the composite.

2.7.7 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is used to examine the surface morphology of a material composite. SEM micrographs can be used to visualize the contact between the matrix and fibres of the composite material. Wang et al., (2019) studied the effect of banana leaf fibre (BLF) on the thermal and mechanical properties of thermoplastic cassava starch (TPCS) under Scanning Electron Microscopy (SEM). The studied shows a variation of the microstructures of each specimen when different fibre contents were loaded. It stated that fibre breakage could be found in all composites as a result of tensile fracture due to good stress-transfer from the matrix to fibre that gave reinforcement effect to the composites. It was observed that more rough fracture at higher fibre content than lower ones. In addition, this studied investigate that no phase separation occurred because there was good adhesion between the matrix and fibre in figure

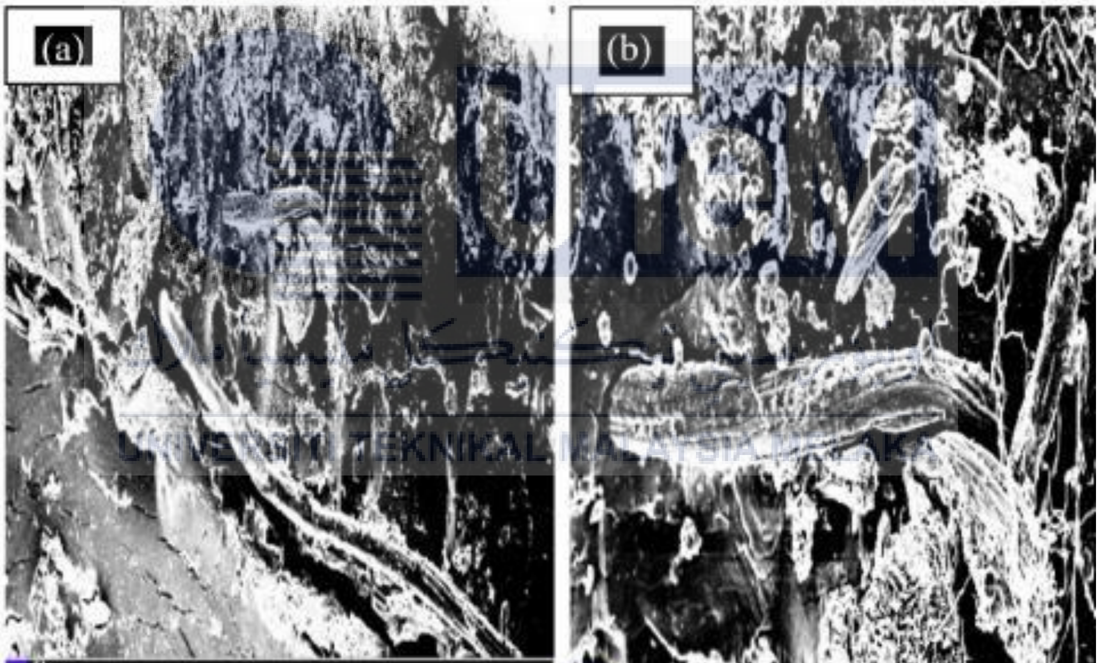


Figure 2.16: SEM micrograph
(Wang et al., 2019)

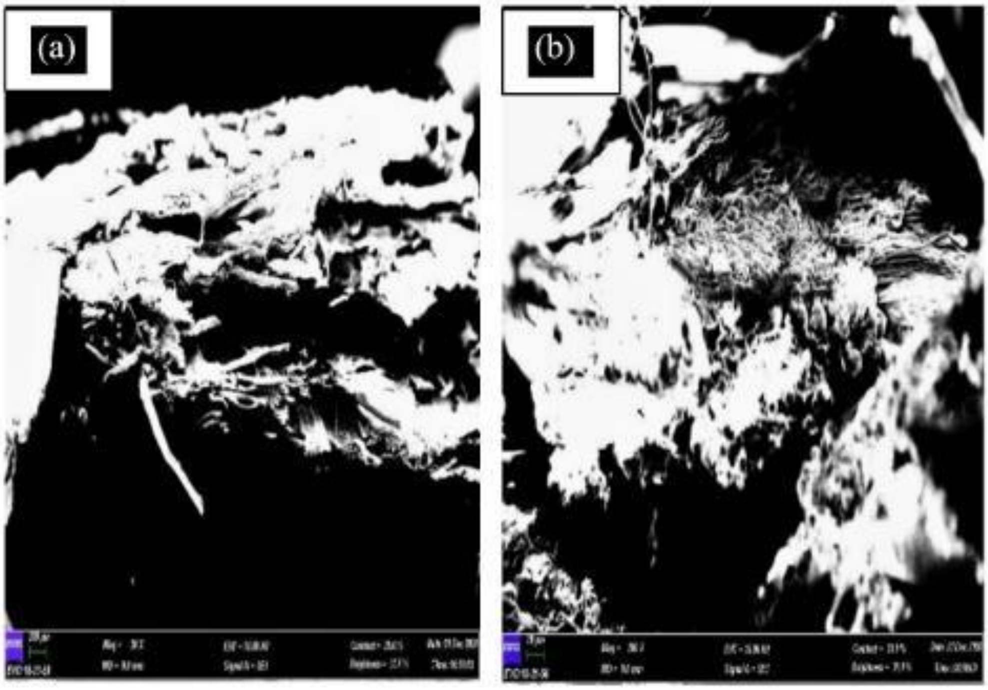


Figure 2.17: Fiber shows in good adhesion (Wang et al., 2019)

This findings also confirmed by Kamaruddin et al., (2022), who found that the addition of fiber will increase the compatibility and will represent by the good fibre wetting of the matrices. This effect could be explained by the identical hydrophilic properties of TPCS and CCF, which result in good adhesion between them. This studies demonstrate the micrograph shows fibre pull-out, and in particular that CCF was more broken (Figure 2.19). This observation could be explained by TPCS and CCF, forming strong intermolecular hydrogen bonds. Hence, composites with a higher CCF content appeared to have a good stress transfer from CCF fibre to the TPCS matrix and thus, subsequently enhanced the mechanical performance of the materials.

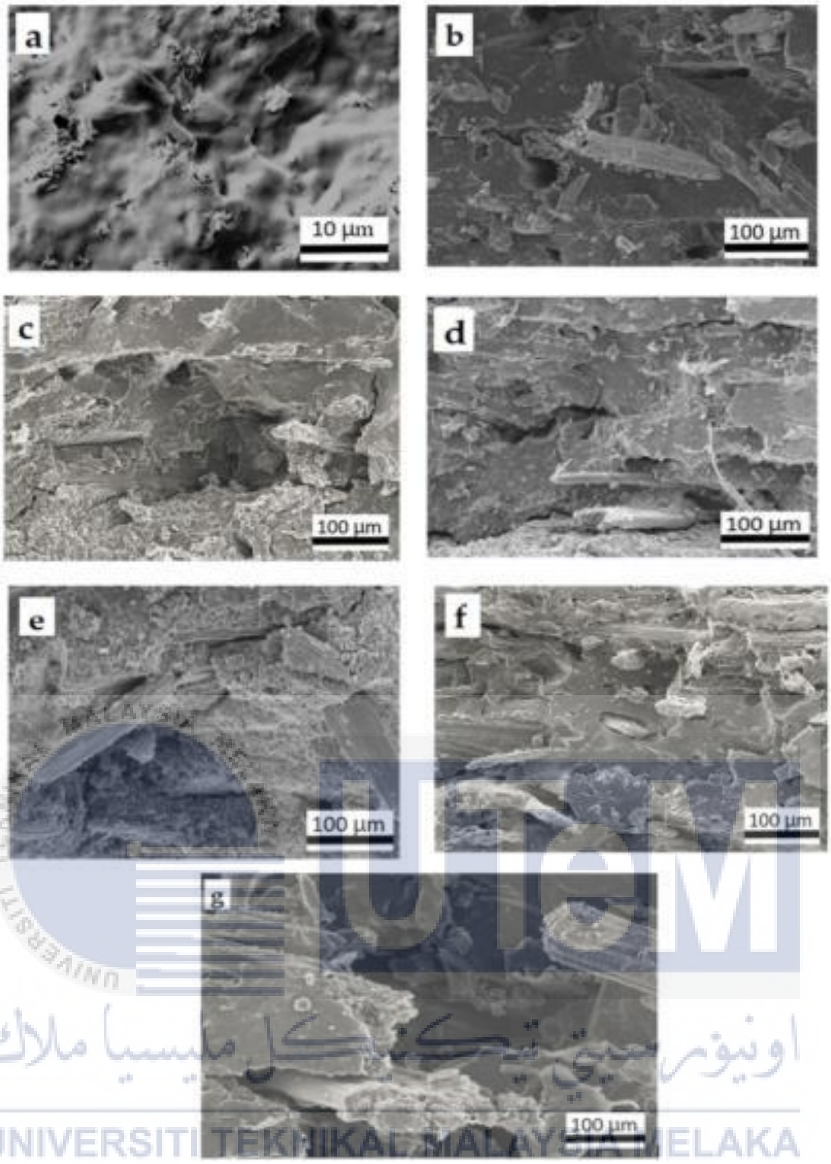


Figure 2.18: SEM micrograph of fractured TPCS/CCF

2.8 Summary and literature review critique

The following hypothesis has been reached based on a study of the literature on natural fibre, composites, starch, thermoplastic starch, palm wax, and plasticizers:

i. The combination of natural fibres into composite materials yields positive environmental outcomes as it involves repurposing waste derived from natural fibres, such as oil palm leaves, and converting it into valuable and practical products.

ii. The reinforcement of thermoplastic starch with natural fibre provides a significant contribution towards minimizing environmental harm, as the resulting biodegradable product readily degrades in soil conditions.

iii. Starch is a natural resource that is both renewable and abundant, and it is the principal source of carbohydrate reserves in plants.

iv. Oil palm leaf fibres can be considered a new sustainable resource for thermoplastic reinforcement.

v. Chemical treatment of the fibre has been found to enhance the interfacial bonding between the fibre and matrix.

Despite the numerous research conducted on thermoplastic starch, it is noteworthy that no studies have explored the incorporation of oil palm leaf fibre into thermoplastic cassava starch/palm wax composites.

2.9 Literature review critique

Based on my understanding, glycerol is an essential plasticizer that improves the flexibility while being safe for the environment. Starch, utilized as thermoplastic starch (TPS), offers a renewable and biodegradable alternative to conventional plastics, owing to its abundance and processing versatility. The inclusion of oil palm leaf fiber (OPLF) not only repurposes discarded palm leaves but also serves as a sustainable reinforcement, enhancing composite mechanical properties while promoting cost-effective and environmentally conscious practices through the utilization of local waste materials. The study reveals the decrease in water affinity, physical testing, environmental testing, and other properties as the natural fibre concentration increase.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The experimental methods utilised in a study on thermoplastic cassava starch reinforcement are described in this section. The study involves a various stages, including selection of materials, fabrication, testing, and data gathering to provide findings. The production procedure, the precise tests carried out to evaluate the raw materials' properties, and the raw materials used to strengthen cassava starch are all explained. The flowchart in Figure 3.1, which gives a clear picture of the sequential stages taken, clearly illustrates the research strategy used in this study.

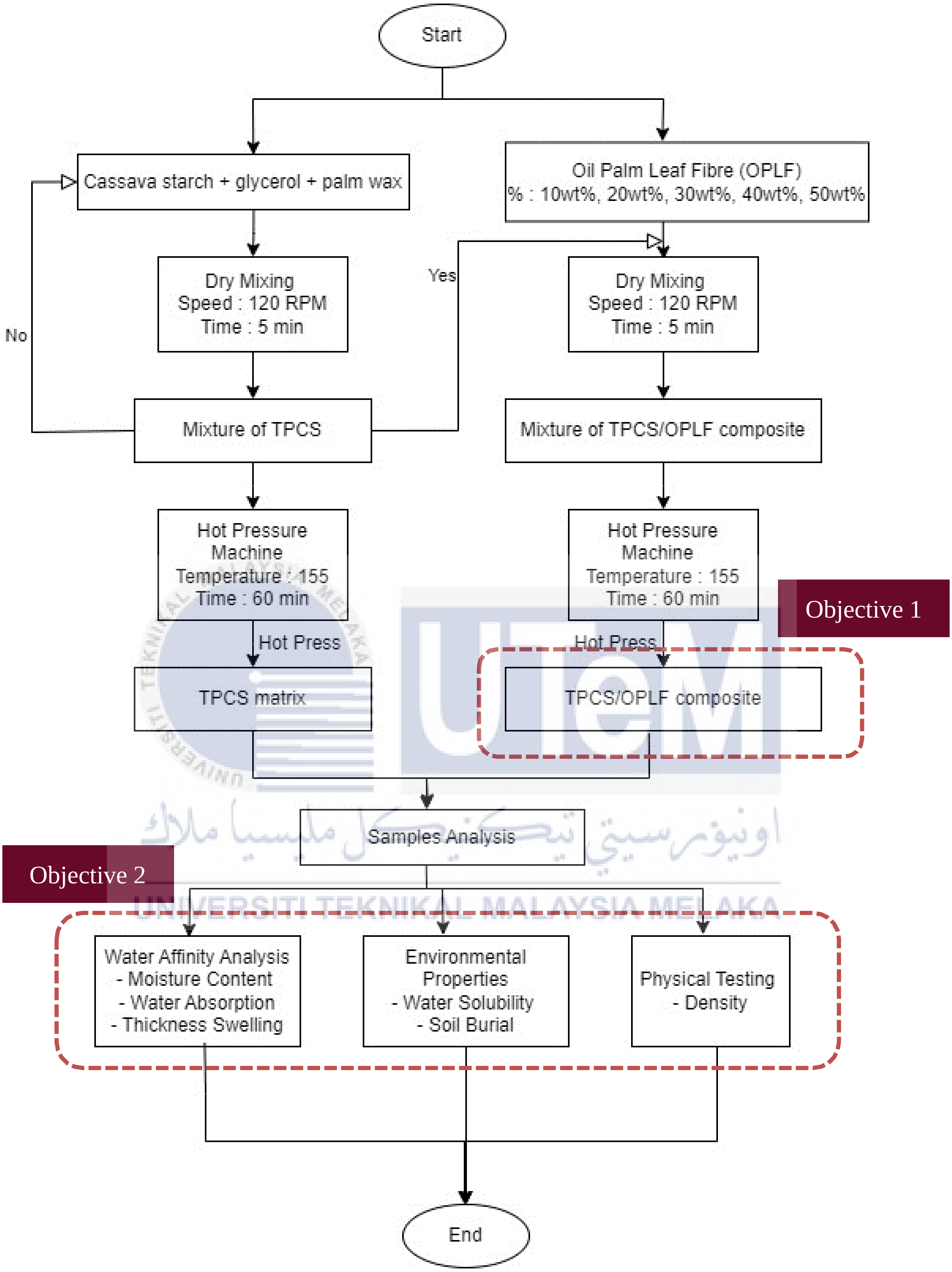


Figure 3.1 Flow of Research Methodology

3.2 Material

3.2.1 Oil Palm Leaf Fibre

The Oil Palm leaf was sourced from a local farm in Negeri Sembilan's Juasseh district. These Oil Palm are quite easy to grow, especially in arid places. The fibres of the oil palm leaf were removed by soaking the oil palm leaf for 2 weeks to soften the fibres, making them easier to separate manually.

After thoroughly cleaning the soaked oil palm leaf, each fibre strand was retrieved. Following that, the collected fibres will be dried in the sun for approximately 24 hours to ensure complete drying. Prior to the grinding process, the fibres will be dried for 24 hours at a temperature of 100°C to remove all moisture from the fibres. Finally, the dry fibres will be grind into short fibre.

Figure 3.2 Oil Palm Leaf

3.2.2 Cassava Starch

The main material of this study is cassava starch which source from supplier Antik Sempurna Sdn. Bhd. Malaysia. Cassava starch is a white powder-like other starch. Figure 3.3 shows the cassava starch that will use in this study.

Figure 3.3 Cassava Starch

3.2.3 Glycerol

The combination of a plasticizer into the study has the potential to significantly enhance the flexibility and overall properties of the product being investigated. In this particular study, glycerol ($C_3H_8O_3$) was chosen as the plasticizer of choice. The glycerol used in the study was specifically produced by QReC (Asia) Sdn Bhd, a renowned supplier in the industry. It is important to note that the glycerol provided by QReC Chemical was of high quality, boasting a purity level of 99.5% AR grade. Additionally, its molar weight was measured to be 92.10 g/mol.

Glycerol, the chosen plasticizer, is a clear and viscous liquid that exhibits a moderate viscosity. Its physical characteristics make it suitable for various applications, particularly as a plasticizer. By introducing glycerol into the study, it is expected that the product's flexibility will be improved, along with other desirable properties.

Figure 3.4 Glycerol with 99.5% AR grade

Table 3.1 Chemical composition of glycerol from QReC Chemical

Chemical Composition	Percentage Value
Assay (Acidimetric)	99.5%
Halogen Compounds (as Cl)	0.003%
Chloride (Cl-)	0.001%
Sulfates (SO4)	0.001%
Insoluble in water	Passes Test
Acidity/Alkalinity	Passes Test
Ammonium (NH4)	0.0015%
Arsenic (As)	0.0001%
Copper (Cu)	0.001%
Heavy Metal (as Pb)	0.0005%
Iron (Fe)	0.0005%
1,2,4-butanorial (G.C)	0.2%
Aldehydes (HCHO)	0.0005%
Zinc (Zn)	0.001%
Nickel (Ni)	0.0005%
Lead (Pb)	0.001%
Sulphated Ash	0.01%
Water	2%

3.2.4 Palm wax

In this study, palm wax, a resinous wax, plays a crucial role. Palm wax exhibits a color spectrum ranging from pale yellow to yellow-tan. The moisture-repellent characteristics of palm wax effectively safeguard the thermoplastic cassava starch from degradation when exposed to moisture. Figure 3.5 shows the palm wax that used for this study.

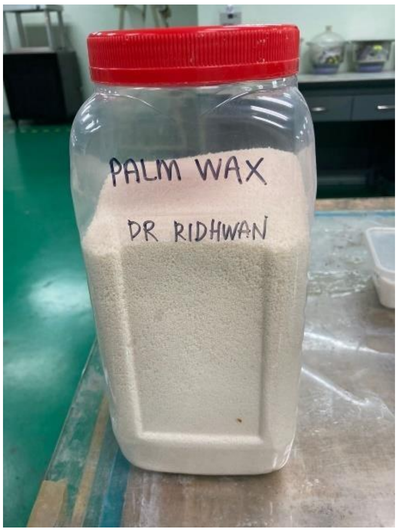


Figure 3.5 Palm Wax

3.3 Preparation of Sample

3.3.1 Preparation of Thermoplasttic Cassava Starch with Palm Wax

In the thermoplastic production process, cassava starch and glycerol will be manually combined. The ratio of cassava starch to glycerol is 100:30 by weight, with 100g of cassava starch and 30g of glycerol. Once the cassava starch and glycerol are evenly dispersed, they undergo dry mixing in a blender set to 120 rpm to ensure thorough mixing of the materials.

Before putting the mixture into the mold, the mixed cassava starch and glycerol was weighted at 58.20g. Then the mold can be put into the hot press machine. The following section required the use of a hot press machine, which must be heated to 155 °C. While the machine was heating up, the mold was prepped by lining it with a Mylar sheet to make the operation of taking the sample mixture from the mold easier.

The mold containing the mixed sample was placed in the hot press machine after the warmed session achieved a temperature of 155 °C. At a temperature of 155 °C, the hot press technique takes an hour. After that, the mixed sample was placed in cooling part for 20 minutes. As a result, the sample mixture exposed to this process was dubbed 100% thermoplastic cassava starch.

The mixture of thermoplastic cassava starch with palm wax are 90% cassava starch mixed with glycerol and 10% palm wax to reduce the moisture sensitivity. Figure 3.6 shows the preparation of thermoplastic cassava starch with palm wax.

Figure 3.6 Preparation and fabrication of thermoplastic cassava starch with palm wax

Figure 3.7 Samples of thermoplastic cassava starch with palm wax

3.3.2 Preparation of Thermoplastic Cassava Starch Reinforced with Oil Palm Leaf Fibre

The production of thermoplastic cassava starch/palm wax composites reinforced with oil palm leaf fibre was achieved by incorporating the previously prepared thermoplastic cassava starch/palm wax composites with oil palm leaf fiber. As mentioned in Section 3.2.1, the oil palm leaf fibre has undergone prior processing. To create the thermoplastic cassava starch/palm wax mixture and incorporate the fiber, the specified fibre percentages of 0%, 5%, 10%, 15% and 20% were followed. For example, 5.82g of fibre (10wt%) and 52.38g of the thermoplastic cassava starch/palm wax matrix were utilized. The materials dried mixed before being placed into the mold.

Subsequently, the mold containing the mixture has been subjected to a hot press machine, set at a temperature of 155°C, for a duration of one hour. This procedure has been replicated for the remaining fibre percentages. By employing this method, the desired thermoplastic cassava starch/palm wax composites with varying fibre percentages were successfully fabricated, facilitating the investigation and evaluation of their properties and performance.

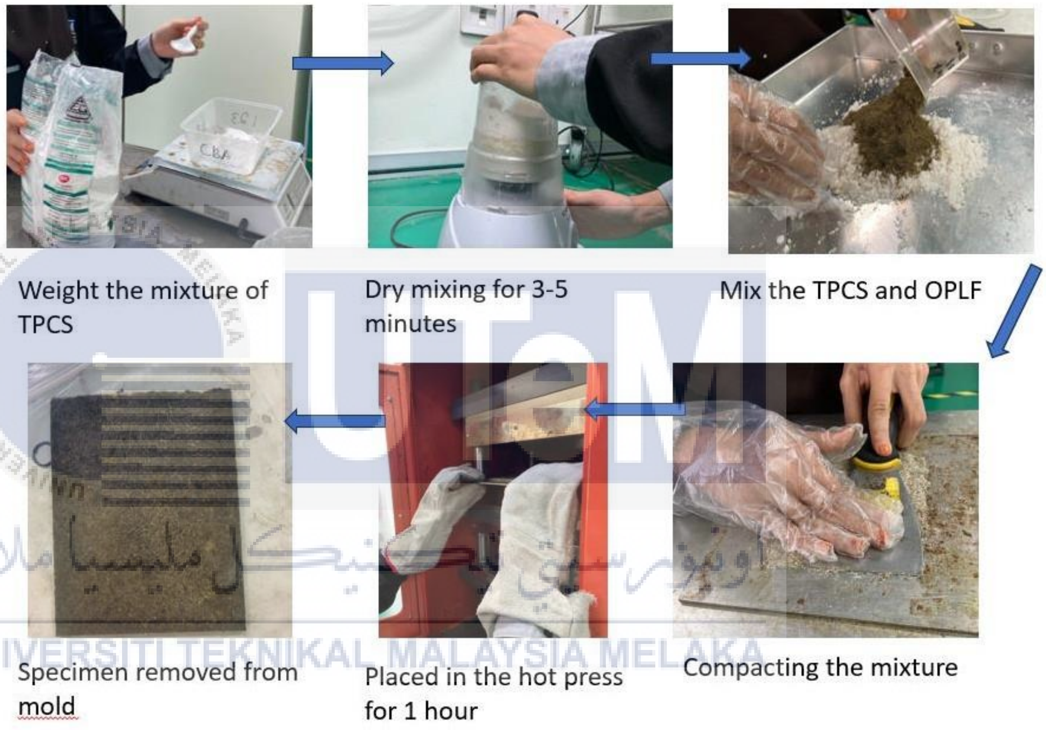


Figure 3.8 Fabrication of Thermoplastic Cassava Starch Reinforced by Oil Palm Leaf Fiber

3.4 Characterization of Samples

3.4.1 Moisture Content

The moisture content determination process was conducted following the same methodology as the previous tests. Five sample pieces, each with dimensions of 10mm x 10mm x 3mm, were carefully prepared. Precise weighing balances were utilized to measure the initial weight (Wi) of the samples. Subsequently, the samples were subjected to a controlled environment in an air circulation oven set at 80 °C for a period of 2 hours to ensure thorough drying. To prevent any moisture absorption from the surroundings during weighing, the samples were promptly removed from the oven and their final weights (Wf) were accurately measured. The moisture content of the samples was determined as a percentage using the prescribed procedure.

$$\boldsymbol{Percentage\ of\ Moisture\ Content}\ (\%) = \frac{\boldsymbol{Wf - Wi}}{\boldsymbol{Wi}}\ \boldsymbol{x\ 100\%}$$


Record the initial weight

Dry in air circulation oven for 8 hours

Record the final weight

Figure 3.9 Methodology of Moisture Content

3.4.2 Water Absorption

Five samples of thermoplastic cassava starch reinforced with oil palm leaf fiber, each measuring 10mm x 10mm x 3mm, underwent the water absorption test. The guidelines outlined in ASTM D570-98 were closely followed in conducting the test, with minor modifications made to accommodate the sample size. The specified dimensions were precisely cut for the samples, which were then placed in an air-circulating oven set at a temperature of 80 °C±2 for a duration of 2 hours. The aim of this drying process was to ensure the elimination of any residual moisture from the samples, preparing them in a dry state before testing.

Subsequent to the drying period, the initial weight (Wi) of the samples was meticulously measured using a high-precision weighing balance. Following this, the samples were immersed in water at room temperature (23 °C±1) for specific durations of 0.5 and 2 hours. After completion of each immersion period, the samples were carefully removed from the water, and their final weight (Wf) was determined using the same precise weighing balance. The percentage of water absorption was calculated utilizing the collected weight data, employing the established methodology described in ASTM D570-98.

$$\boldsymbol{Percentage\ of\ Water\ Absorption}\ (\%) = \frac{\boldsymbol{Wf - Wi}}{\boldsymbol{Wi}}\ \boldsymbol{x\ 100}\%$$

Figure 3.10 Methodology of Water Absorption

3.4.3 Thickness Swelling

The thickness swelling test was conducted in accordance with the guidelines outlined in the ASTM D570-98 standard, with necessary adjustments made to accommodate the sample size. Slicing of the thermoplastic cassava starch samples reinforced with palm wax, measuring 10mm x 10mm x 3mm, was required for the test. These samples underwent a comprehensive drying process in an air circulation oven set at a controlled temperature of 80°C±2 for 2 hours to completely remove moisture.

Following the drying process, precise measurements of the samples were taken using a Vernier Caliper (Mitutoyo model) with a precision of 0.01 cm, providing initial measurements (Ti). Subsequently, the samples were immersed in water at a consistent room temperature of 23°C±1 for specific durations of 0.5 hour and 2 hours. After each immersion period, final measurements (Tf) were taken using the same Vernier Caliper. The calculation of the percentage of thickness swelling utilized the designated formula specified in the ASTM D570-98 standard, ensuring the accuracy and standardization of results.

$$\boldsymbol{Percentage\ of\ Thickness\ Swelling}\ (\%) = \frac{\boldsymbol{Tf - Ti}}{\boldsymbol{Ti}}\ \boldsymbol{x\ 100}\%$$

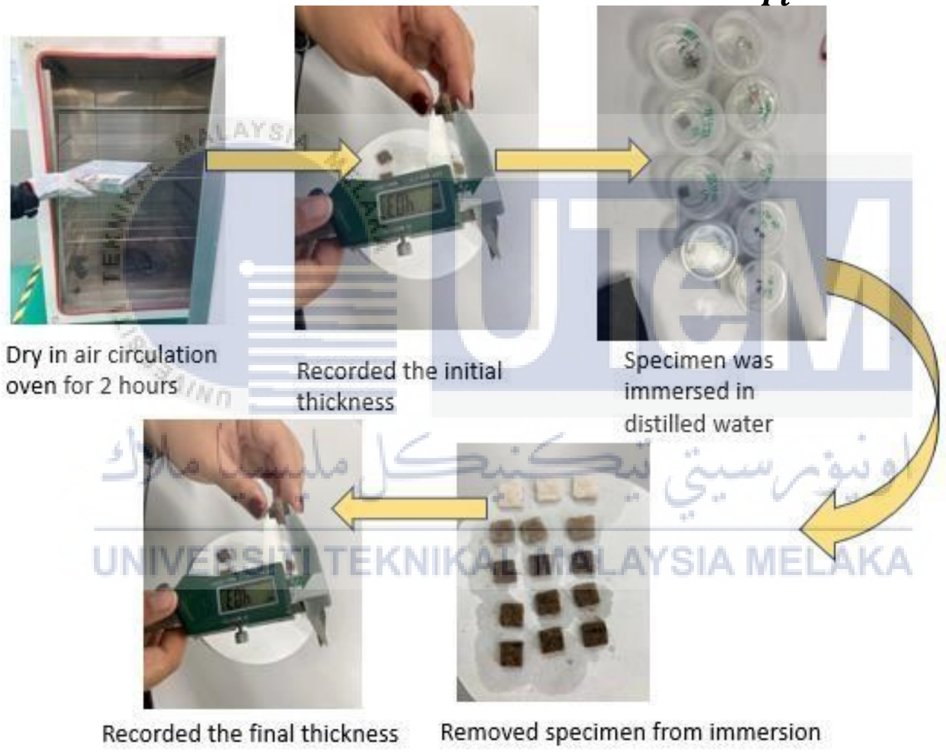


Figure 3.11 Methodology of Thickness Swelling

3.4.4 Water Solubility

Based on the water solubility study conducted by Kamaruddin et al. (2023), the adjustment in the sample preparation process was referenced. Consistency was ensured by meticulously cutting the specimens into dimensions of 10mm x 10mm x 3mm. The initial weight (Wi) of each sample was accurately measured using a precise weighing scale.

Subsequently, the samples underwent a comprehensive drying process in an air circulating oven set at a controlled temperature of 80°C±2 for 2 hours. This crucial step aimed to eliminate any residual moisture before further testing commenced.

Following the drying period, the samples were immersed in 30 ml of distilled water and gently stirred to facilitate water absorption. After precisely 24 hours, the samples were carefully removed from the container, and excess water on the sample surface was absorbed using filter paper. An additional 24-hour drying period in the air circulating oven at 80°C±2 was performed.

Determining the final weight (Wf) of each sample was followed by calculating the weight reduction percentage using the appropriate formula. This calculation served to quantitatively assess the weight changes resulting from the water solubility testing, offering valuable insights into the samples' behavior when exposed to water.

$$\boldsymbol{Percentage\ of\ Weight\ Reduction}\ (\%) = \frac{\boldsymbol{Wf - Wi}}{\boldsymbol{Wi}}\ \boldsymbol{x}\ \mathbf{100}\%$$

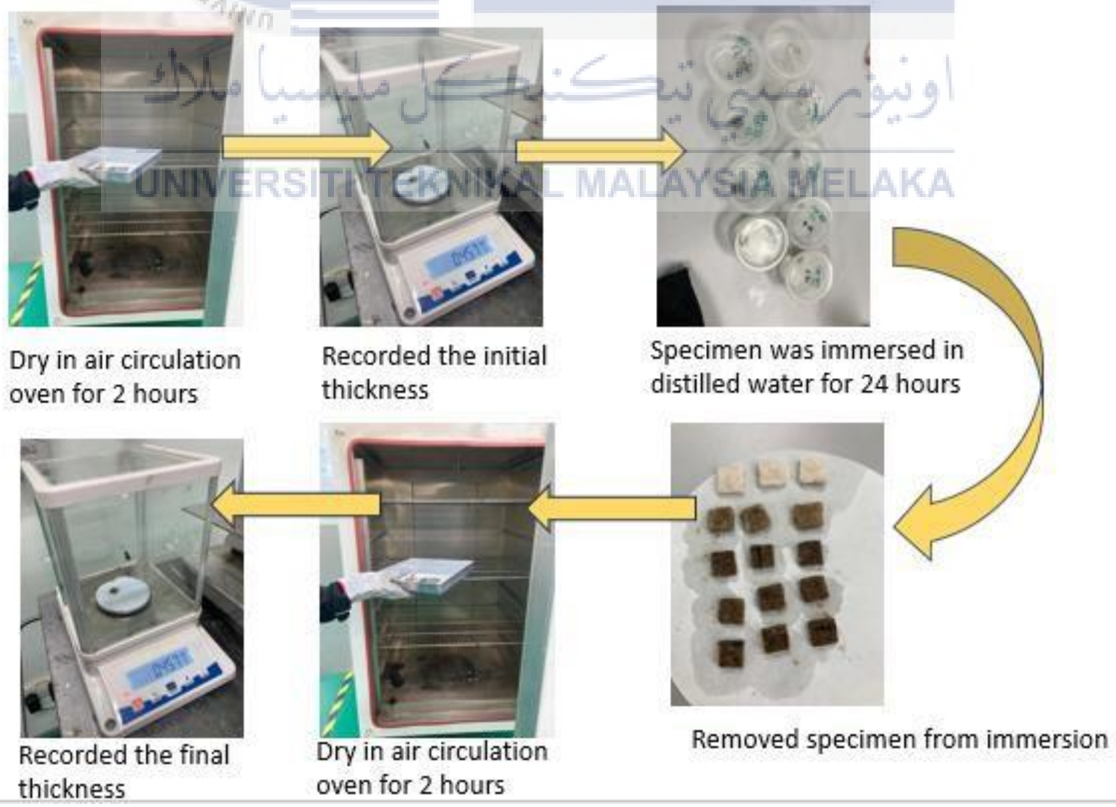


Figure 3.12 Methodology of Water solubility

3.4.5 Soil Burial

According to the research conducted by Kamaruddin et al. (2022), which explored the properties of a cassava starch-based biodegradable composite reinforced with Cymbopogan Citratus Fiber, this study aimed to investigate the degradation behavior of the samples through a soil burial test. Consistent with their methodology, each formulation consisted of five samples, each measuring approximately 15mm x 15mm x 3mm. These samples were cut into equal-sized pieces with dimensions of 15mm x 15mm x 3mm. The initial weight (Wi) of each sample was determined using a precise weighing balance, followed by a 2-hour drying process in an air circulating oven set at 80°C to eliminate any moisture content.

The samples were buried in a soil mixture composed of a 50/50 blend of sand and soil, at a burial depth of 10cm. Throughout the test duration, the temperature was maintained at a constant 30°C. To ensure consistent moisture levels, 400 ml of water was added to each 1250g soil mixture every three days, maintaining the initial water content of the soil. Plastic mesh was employed to facilitate the retrieval of samples from the soil burial process prior to burial, allowing interaction between microorganisms, moisture, and the soil samples. The experiment consisted of two assessment periods, one lasting four weeks and another lasting eight weeks.

After the designated time periods, the soil samples were carefully extracted from the burial site and rinsed with distilled water to remove any contaminants. Subsequently, the samples underwent a 2-hour drying process in an air circulating oven set at 80°C, enabling their weight to be measured and the final weight (Wf) to be determined. The percentage weight loss was calculated using the methodology specified in ASTM D 6003-96, which evaluates mass loss during soil burial tests, providing insights into the degradation of the samples under soil burial conditions.

$$\boldsymbol{Percentage\ of\ Weight\ Loss}\ (\%) = \frac{\boldsymbol{Mf - M}}{\boldsymbol{Mi}}\ \boldsymbol{x\ 100\%}$$

Figure 3.13 Methodology of Soil Burial

3.4.6 Density

The density testing methodology employed in that study strictly adhered to the guidelines specified in the ASTM D 1895 standard. To ensure accuracy and consistency, the samples were precisely chopped into dimensions of 10mm x 10mm x 3mm, considering their suitability for the test requirements. Subsequently, the samples underwent a thorough drying process in an air-circulating oven, meticulously set at a controlled temperature of 105°C±2 for a duration of 24 hours. This critical step was essential for eliminating any lingering moisture from the samples, thereby facilitating precise density measurements.

After the drying process, the samples were carefully placed in a desiccator containing granulated silica gel to ensure their thermal equilibration with the ambient environment. Following equilibration, the samples were meticulously weighed using a high-precision weighing scale, while their volume was determined volumetrically. The weight measurements were obtained using a Vernier Caliper of Mitutoyo model, known for its accuracy of 0.01 cm. The volume of the samples was calculated employing the appropriate formula relevant to the sample shape. By combining the weight and volume data, the density of the samples could be accurately determined, providing valuable insights into theirphysical properties and characteristics.

$$\boldsymbol{Density}\ \frac{(\boldsymbol{g})}{\boldsymbol{cm3}} = \frac{\boldsymbol{mass}(\boldsymbol{m})}{\boldsymbol{volume}(\boldsymbol{v})}$$

Dry in air circulation oven for 2 hours

Recorded volume and weight specimen

Figure 3.14 Methology of Density

3.4.7 Scanning Electron Microscopy (SEM)

The purpose of using scanning electron microscopy (SEM) equipment is to determine the morphology of thermoplastic casava starch reinforced with oil palm leaf fiber samples. The scanning electron microscope (SEM) used is a Zeiss Evo 18 Research from Germany.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This section provides an overview of the results and discussion obtained from the fabrication of samples and the outcomes of various tests conducted in this study. The research focuses on three main areas: environmental testing, water affinity testing, and physical testing. Environmental testing involves assessing the performance and durability of materials under different environmental conditions, while water affinity testing aims to understand the interaction between the material and water. Physical testing, specifically the density test, provides insights into the material's compactness and suitability for specific applications. These tests contribute to the overall understanding of the materials' behavior, properties, and potential applications.

4.2 Water Affinity Testing

4.2.1 Moisture Content

Moisture content analysis is a crucial step in evaluating the thermoplastic cassava starch composite (TPCS) matrix and its composite with oil palm leaf fiber (OPLF). The presence of moisture within the composite material can significantly impact its performance. Therefore, this study aims to quantify the moisture content in TPCS/OPLF samples. A high moisture content can adversely affect the composite's stability, including factors such as tensile strength, porosity formation, and dimensional stability. Hence, an ideal composite should possess a reduced moisture content.

Figure 4.1 shows the moisture content of Thermoplastic Cassava Starch (TPCS) reinforced with Oil Palm Leaf Fibre (OPLF). TPCS/OPLF0 shows the highest moisture content of 7.62 wt.% for TPCS/OPLF5 and 6.00 wt.% shows the lowest moisture content in TPCS/OPLF20. The results show the fiber incorporation reduces the moisture content of the composite. Additionally, the inclusion of OPLF, ranging from 5% to 20%, significantly affect the moisture content of the composite material. This might be due to the fact that OPLF is less hydrophilic than the TPCS matrix combination. There are has significant difference exists between the mean data for one level composite and the mean data for another level composite. Because the P-value is less than 0.05. Result in this study aligns with the results from Kamaruddin et al. (2023) concerning Cymbopogan citratus fiber reinforcement within TPCS composites, showing a reduction in moisture content with increasing fiber content. These findings highlight the effect of natural fibers on the moisturecontent of composite materials.

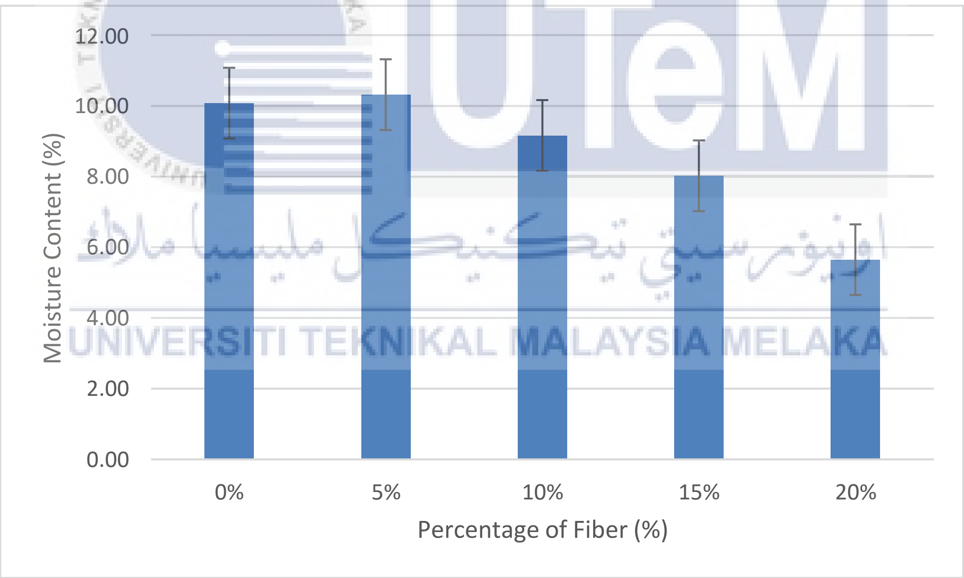


Figure 4.1 Percentage of Moisture Content of TPCS/OPLF with different fiber loading

Table 4.1 The analysis of variance (ANOVA) of moisture content

Variables	df	Moisture Content
Mixture	4	<0.001

4.2.2 Water Absorption

Water absorption testing plays a pivotal role in the characterization of composite materials. It enables the determination of water uptake under specific conditions. Moisture diffusion within composites is influenced by various factors, including voids, fiber volume fraction, temperature, humidity, and matrix viscosity (Kabir et al., 2012).

In this study, the hydrophilic nature of cellulose in oil palm leaf leads to moisture absorption. It shows the presence of fiber reduced the proportion of water absorbed, as starch is more hydrophilic than cellulose fiber, which suggesting that the inclusion of fiber may decrease the hydrophilicity of the starch matrix (Kabir et al., 2012).

Figure 4.2 shows the water absorption capacity of the TPCS matrix and its composites after immersion 0.5 hours and 2 hours. It can be seen that the addition of different amount of oil palm leaf fiber into starch matrix decrease the water uptakes of the material. According to the graph, a fibre concentration of 0% for 2 hours indicates that the higher water absorption which 93.30%. However, the proportion changes when OPLF is included. The presence of fibre reduces the amount of water absorbed owing to the fact that starch is more hydrophilic than cellulose fibre, implying that the presence of fibre may reduce the hydrophilicity of the starch matrix (Kabir et al., 2012). Thus, result shows lowest water absorbed in the specimen is fiber with 20% valued as 10.5% and 52.6% for 0.5 hour and 2 hour respectively. There are has significant difference exists between the mean data for one level composite and the mean data for another level composite shown in table 4.2. Because the P-value is less than 0.05.

The hydrophilic nature of oil palm leaf fibre allows for the free diffusion of water molecules within the composite material. Jumaidin et al., (2019) employed water absorption testing to measure water uptake in composites of sugarcane fiber reinforce thermoplastic potato starch (TPPS). Similarly, Kaewtatip & Thongmee, (2012) conducted a study on the influence of Luffa Fibre Loading on thermoplastic starch properties, revealing the significant influence of fiber content and adhesion on the water absorption behavior of the composite materials.

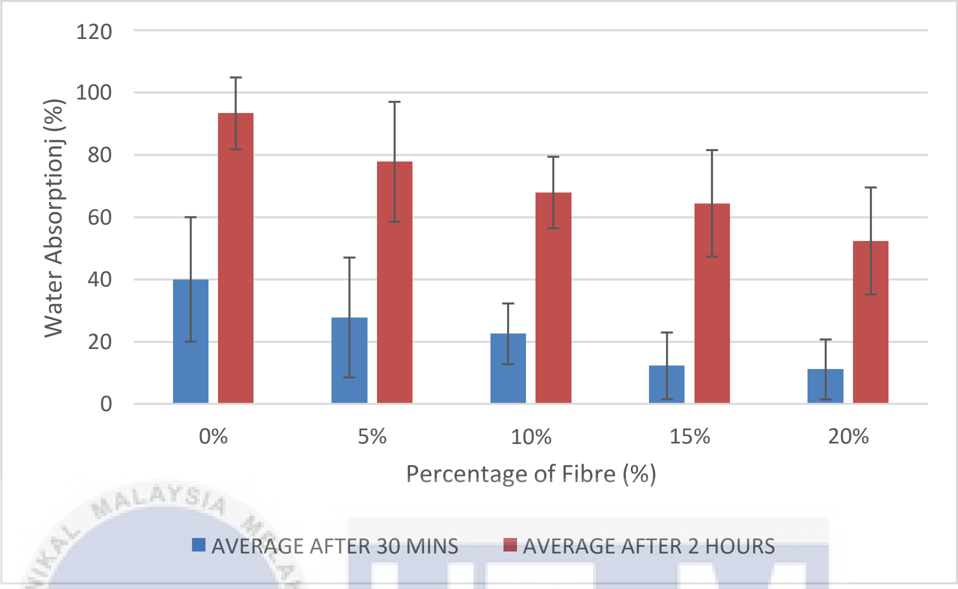


Figure 4.2 Water absorption result for TPCS reinforced with oil palm leaf fiber

Table 4.2 The analysis of variance (ANOVA) of water absorption

Variables	df	30 minutes	2 hours
Mixture	4	<0.001	<0.001

4.2.3 Thickness Swelling

The objective of conducting a thickness swelling test is to evaluate the swelling ratio of a material when immersed in water for a specific duration. This test provides valuable insights into the dimensional stability changes of the material, which is crucial for assessing its overall performance. In the present study, the thickness swelling technique was employed to examine the dimensional stability alterations of TPCS (Thermoplastic Cassava Starch) with the inclusion of oil palm leaf fibre composite.

Figure 4.3 shows the thickness swelling percentage of the TPCS following the incorporation of OPLF after immersion for 0.5 hours and 2 hours . The samples with higher fiber proportion was found to swell less. . For 30 minutes and 2 hours, the amount of thickness swelling of the specimen with 0 wt% fiber is 22.1% and 53.1%, respectively, and for the lowest percentage of thickness swelling specimen with 20 wt% fiber is 9.6% for 30 minutes and 38.3% for 2 hours, respectively. Table 4.3 shows there are has significant difference exists between the mean data for one level composite and the mean data for another level composite. Because the P-value is less than 0.05.

This finding indicates that as the percentage of fiber loading increases, the swelling of the specimen diminishes, due to voids within the specimen, as supported by Zuhudi et al. (2021). Consequently, integrating OPLF results in a reduced swelling ratio compared to pure TPCS. This effect can be seen after 30 minutes of immersion, however it become more significant after 2 hour immersion. The presence of fibers with a rigid structure than starch accounts for this outcome, enhancing the dimensional stability of the composites. Additionally, voids within the composite impact the specimen's dimensional stability, potentially leading to delamination as water is absorbed (Saw et al., 2014).

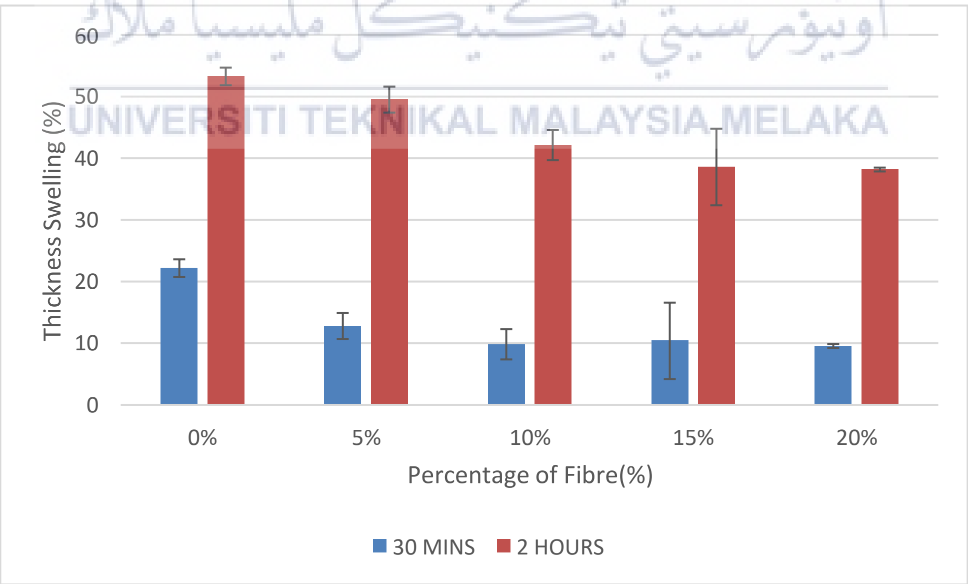


Figure 4.3: Thickness swelling of TPCS/OPLF

Table 4.3 The analysis of variance (ANOVA) of thickness swelling

Variables	df	30 minutes	2 hours
Mixture	4	0.02	<0.001

4.2.4 Water Solubility

The aims of conducting a water solubility test is to assess the weight loss of a material when continuously stirred in water for a specific duration. As highlighted in the study by Adam et al., (2019) water solubility provides insights into the material's decomposition behaviour when exposed to water. Therefore, the water solubility test aims to evaluate the water resistance of the TPCS (Thermoplastic Cassava Starch) matrix after incorporating the oil palm leaf fibre composite.

Figure 4.4 presents the water solubility analysis of TPCS/OPLF composites, illustrating the materials' resistance to water immersion and continuous stirring. Addition of oil palm leaf fiber into TPCS diminished the composite's solubility in water. The water solubility increased from 37.7% for TPCS matrix to 41.3% for TPCS/OPLF-5 and 44.00% for TPCS/OPLF-10 but slightly decreased from 44.00% to 30.70% for TPCS/OPLF-20. The decreased solubility compared to neat TPCS is due to TPCS/OPLF's enhanced water resistance, preventing material disintegration and dissolution by impeding water absorption. There are has significant difference exists between the mean data for one level composite and the mean data for another level composite. Because the P-value is less than 0.05. According to the study by (Jumaidin et al., 2019), the lower solubility of the composite materials compared to the pure TPCS could potentially be ascribed to the greater water resistance exhibited by natural fibers. This characteristic contributes to impeding water absorption, thereby preventing the disintegration and dissolution of the materials.

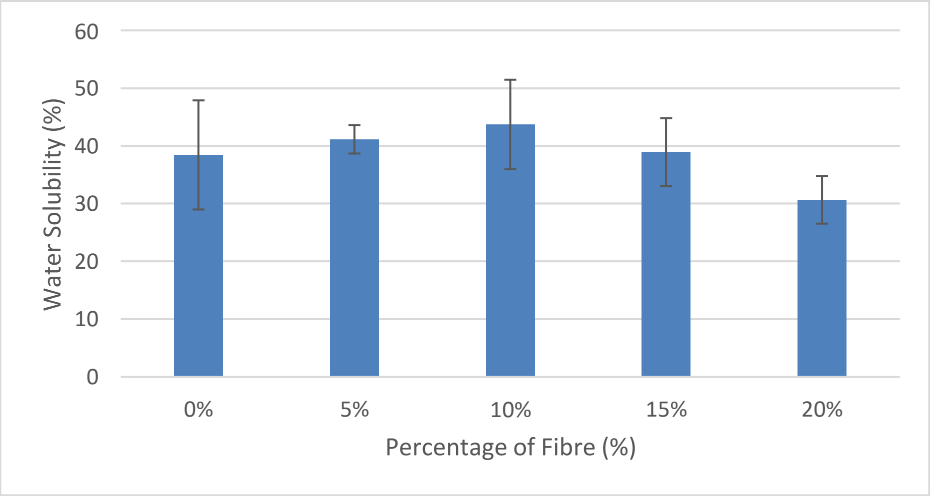


Figure 4.4 Result of Water Solubility of TPCS/OPLF with different percentage of fiber loading

Table 4.4 The analysis of variance (ANOVA) of water solubility

Variables	df	Water Solubility
Mixture	4	<0.001

The presence of fibre play a vital role in strengthening materials by creating a network within composites. The fibers interact with starch chains through their hydroxyl groups, forming strong bonds that enhance the stability of the composite. This interaction, observed in studies by Adam et al., (2019), and Jumaidin et al., (2019), reduces water sensitivity and solubility of the composite, making it more resistant to dissolution. Essentially, the incorporation of the fibers improves the overall strength and durability of the biopolymer matrix in the composites.

4.2.5 Soil Burial

Soil burial tests serve as a valuable method for assessing the biodegradation rate of materials. These tests show a crucial role in measuring the weight loss of material composites during the burial process. The primary objective of developing new materials, as highlighted by Bootklad & Kaewtatip, (2013) is to ensure their easy disintegration in the natural environment. Various factors, including soil pH, temperature, presence of microorganisms, humidity, and the composition of the material, contribute to the degradation process.

Figure 4.5 shows that at the first 4 and 8 weeks of testing days for 0-20 wt.% fiber, the overall results shows a reduction in the mass of the specimen. The graph demonstrates that fibre content of 5% achieved the highest weight loss throughout the four weeks after burial, at 59.9 wt.%. However, 20% fibre content results in the lowest proportion of weight loss at 32.2 wt.%, whereas the graph pattern indicates that weight loss decreased as fibre content increases. This indicates that the presence of OPLF influenced the pace of composite breakdown. Thus, there are has significant difference exists between the mean data for one level composite and the mean data for another level composite. Because the P-value is less than 0.05.

The incorporation of oil palm leaf fibre from 0-20wt% shows the reduction of biodegradation rate of the composite, leading to a lower weight loss. This observation attributed to the less hydrophilic nature of the natural fibre compared to the thermoplastic starch matrix, as reported by Curvelo et al., (2001). This findings shows that the OPLF more resistance to biodegradation compared to TPCS matrix. This is due to the increasing in hygroscopic attributes of the material promotes the growing of microorganisms during degradation and because of that, the weight loss of material increases (Maran et al., 2014). Similar findings were also reported by (Jumaidin et al., 2020) for cogon grass/thermoplastic potato starch composites.

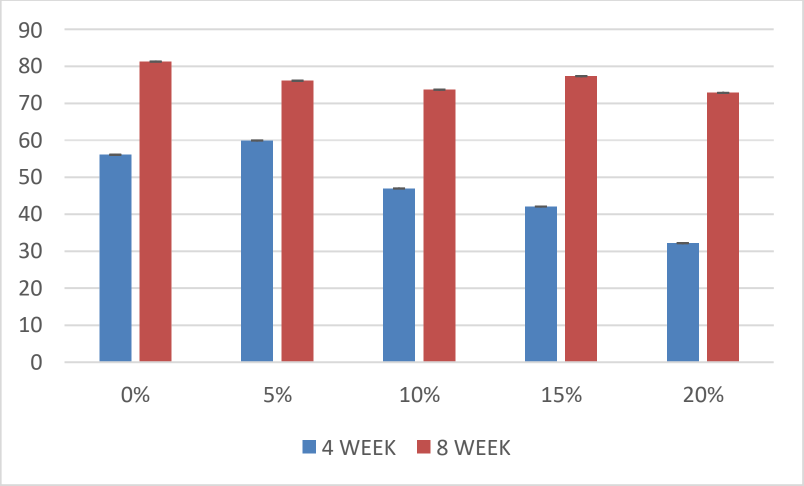


Figure 4.5 Soil Burial of TPCS/OPLF samples

Table 4.5 The analysis of variance (ANOVA) of soil burial for 4 weeks and 8 weeks

Variables	df	4 weeks	8 weeks
Mixture	4	0.001	<0.001

4.3 Physical Testing

4.3.1 Density

Density testing plays a crucial role in the development of composite materials because it has a direct effect on a number of product properties. The density of a composite material influences its weight, usability, energy consumption, transportation expenses, and manufacturing and handling procedures. Obtaining a lightweight composite material is frequently the primary goal in its fabrication, making density testing vital.

The density of TPCS in combination with OPLF is shown in Figure 4.6. Generally, it was noticed that the density slightly decreases as the fibre content increases. There are has significant difference exists between the mean data for one level composite and the mean data for another level composite. Because the P-value is less than 0.05. Based on the result figure 4.6 demonstrates that including OPLF altered the density of the composite material. At 0% OPLF content, the density gained is 1.215 g/cm3, whereas at 20% OPLF content, the density gained is 1.055 g/cm3. This condition might be the presence of voids in the composite material as a result of raising the fibre content percentage. This can refer to sem figure 4.9 (a). This result is consistent with the findings of a similar study Nazri et al., (2020) on Thermoplastics Corn Starch (TPCS) Reinforced Pineapple Leaf Fibre (PALF) Composite. According to Kamaruddin et al., (2023) the rising porosity of starch-based biodegradable composites supplemented with date palm and flax fibres is caused by an inadequate matrix covering the fibres' surface. Thus, voids emerge as a result of increased fibre loading in composite materials.

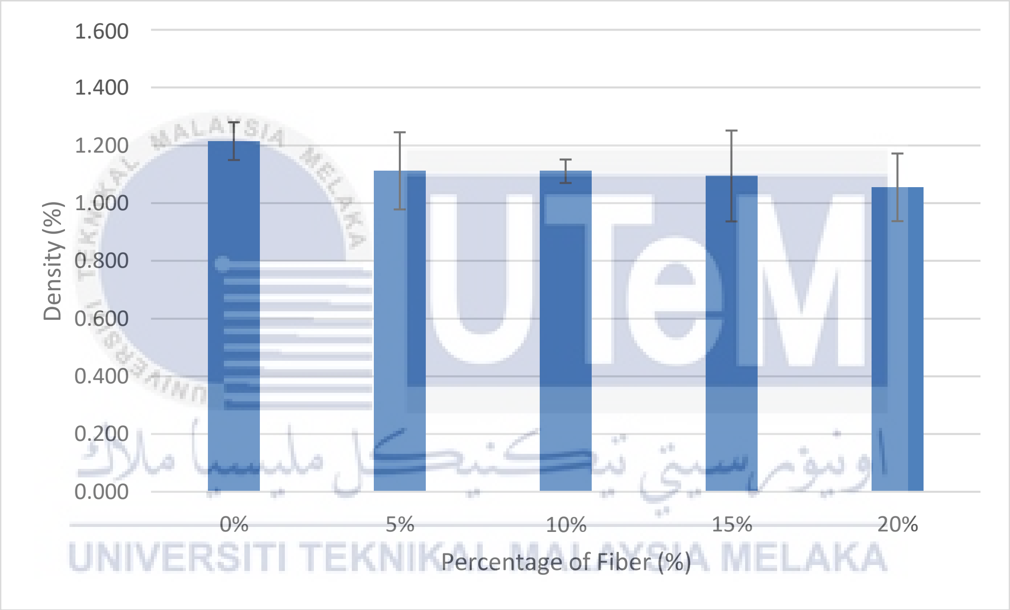


Figure 4.6 Density of TPCS/OPLF composite with different percentage of fiber loading

Table 4.6 The analysis of variance (ANOVA) of density

Variables	df	Density
Mixture	4	0.01

4.3.2 Scanning Electron Microscopy (SEM)

Scanning Electron Microscope (SEM) is a versatile instrument to verify and analyze microstructure morphology. By performing this test, the contact between the matrix and fibres of the composite material can be observed. Figure 4.7 shows the SEM micrograph of oil palm leaf fibre, while Figure 4.8 (a, b) show pure TPCS and Figure 4.9 (c, d, e and f) exhibit the microstructures surface of TPCS reinforced with oil palm leaf fibre composite with different fibre contents (0, 5, 10, 15, 20 wt.%). The findings showed a variation of the microstructures of each specimen when different fibre contents were loaded.

Figure 4.7 depicts the scanning electron microscopy (SEM) image of OPLF, revealing a fiber characterized by a non-uniform composition and a surface displaying rough textures. This might be due to the absence of any chemical treatment applied to the fiber during its processing phase (Teixeira et al., 2009).

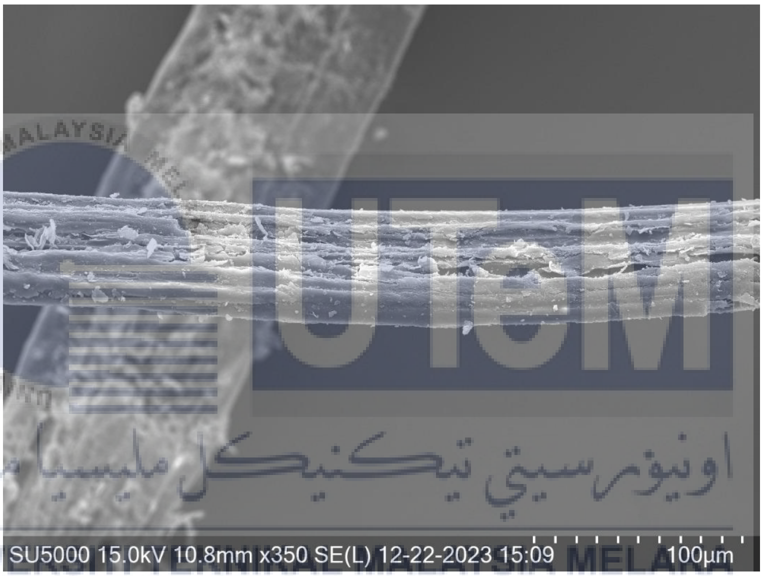


Figure 4.7: SEM micrograph of oil palm leaf fiber.

The TPCS/OPLF-0 is depicted in Figure 4.8(a) and 4.8(b) only consisted of TPCS. Figure 4.8(a) and (b) present different magnifications for the specimen, 20× and 500×, respectively. From the results in Figure 4.8 a,b, it can be seen that only matrix that composed of starch and glycerol can be found in the specimen. In addition, no remaining starch granules were observed, which might be associated with the good shear force induced by glycerol addition that led to great plasticiser dispersion (Ren et al., 2018). In this photomicrograph, a remarkable finding was that a part of the mixture between starch, palm wax and glycerol had formed a granular structure. According to Kamaruddin et al., (2022), the addition of starch and glycerol by dry mixing method enhances the plasticization of cassava starch, resulting in neat TPCS samples exhibiting a compact and uniform surface without the reinforcement of Oil Palm Leaf fibers.

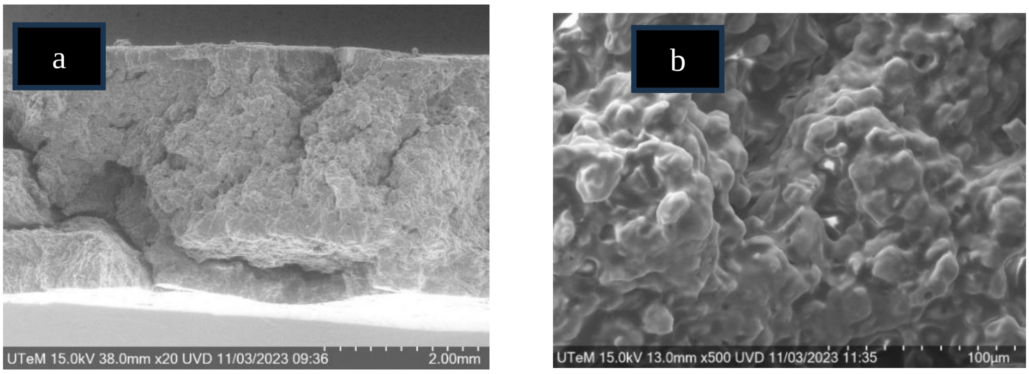


Figure 4.8: SEM micrograph of pure TPCS

Figure 4.9 (c) and (d) show the scanning electron microscopic (SEM) showed the surface for 5% and 10% oil palm leaf fibre contained on the TPCS composite specimen respectively. The micrograph of 4.9(c) and (d) shows the presence of void and crack were visible. A crack line can be found on the specimen, acting as phase separation (Mogan et al., 2023). The micrograph also shows the fibre breakage at 4.9(d) sample.

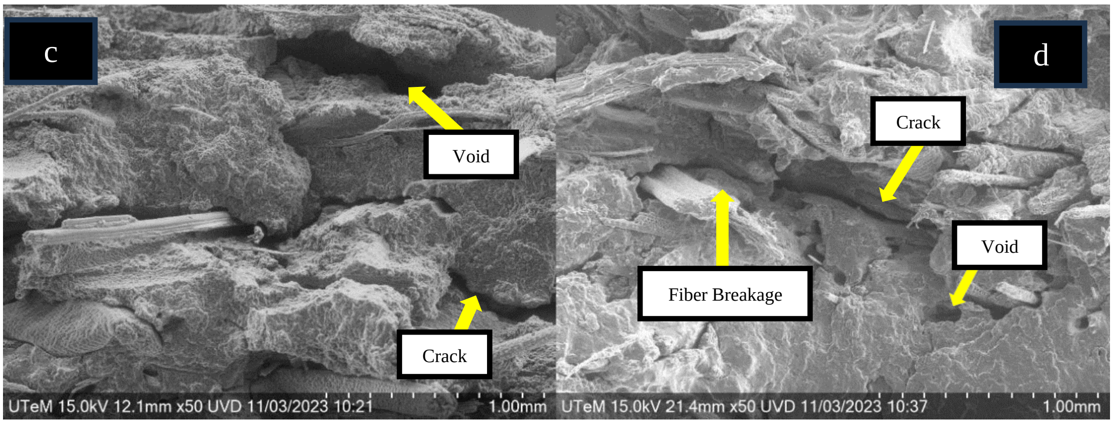
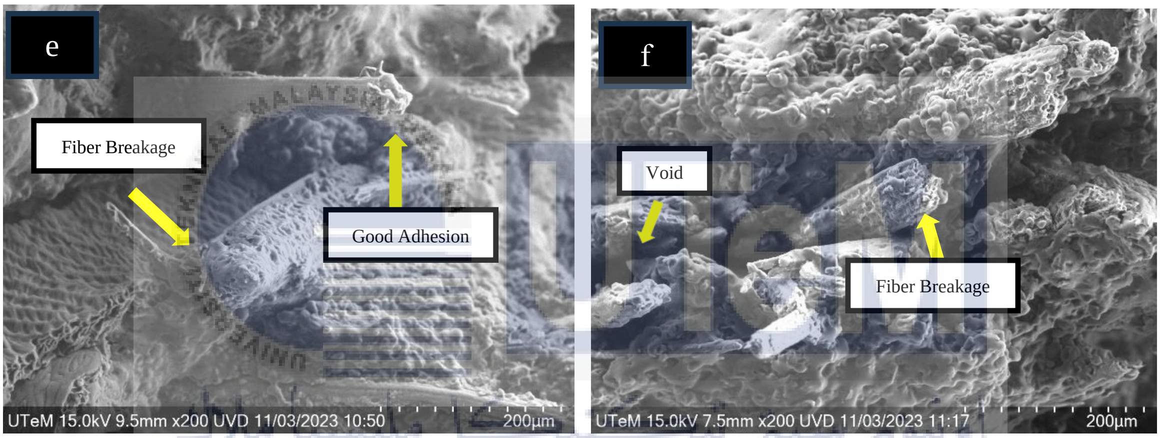


Figure 4.9: SEM micrograph of TPCS/OPLF-5 and TPCS/OPLF-10

Figure 4.9 (e) and (f) shows the SEM micrograph of TPCS/OPLF-15% and TPCS/OPLF-20% respectively. Fig. 4.9 (e) and (f) indicate fiber breakages and voids on the fracture surface. The presence of a clean fiber breakage supporting the enhanced fiber-matrix adhesion (Ren et al., 2018). TPCS and OPLF were highly compatible, as represented by the good fibre wetting of the matrices (Figure 4.9e, f). This behaviour might be explained by the same hydrophilic properties of TPCS and OPLF, which result in good adhesion between them. Likewise, this study is confirmed by a comparable pattern of fibre breakdown seen in TPS/Kenaf and TPS/- sugar palm fibre biocomposites (Zainuddin et al., 2013).



4.4 Fabrication of Packaging Tray

This study developed a Oil Palm Leaf fiber packaging tray at the end of the discussion. Themethodology of fabricating the prospective product with dimensions of 12cm x 12cm x 1cm.The method started with the physical mixing of four main ingredients: cassava starch, palmwax, glycerol, and OPLF. Following that, continue blending with the blender until the mixture is homogeneous. In this manufacturing technique, fiber content of 20% was used. The mixture was then put on a mold lined with Mylar film to facilitate removal. Following that, the mold was put in a hot press machine set to 155 ºC for 1 hour and then cooled for 20 minutes.

Figure 4.10 Fabrication of Packaging Tray TPCS/OPLF

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Numerous research has emphasized the development of environmentally sustainable and sustainable materials. This chapter describe the development process of a new material derived from cassava starch, which focusing on its primary objectives and outcomes.Various assessments, including water affinity testing, environmental properties and physicaltesting have been carried out. This study has three primary aims and findings of which are presented below.

I. **To produce biodegradable composite fiber from thermoplastic cassava starch reinforced with oil palm leaf.**

The development of a biodegradable thermoplastic composite was achieved through the process of dry mixing and hot pressing. This composite material was derived from cassava starch with OPLF. Samples of TPCS with varying percentages of OPLF loading were fabricated to investigate the physical and environmental characteristics associated with each loading percentage.

II. **To evaluate the water affinity properties and the environmental properties of the biodegradable thermoplastic cassava starch reinforced with Oil Palm Leaf fibre.**

The study demonstrated a correlation between the increase in fiber content and a consequential decrease in both water absorption and moisture content percentages. Specifically, at a 20% fiber loading, the moisture content reduced, reaching a value of 5.65%. Similarly, water absorption decreased noticeably, which values of 11% and 52% for 30 minutes and 2 hours, respectively, at the same 20% fiber concentration. Moreover, thickness swelling exhibited a diminishing trend across the board, showcasing decreased swelling percentages as the fiber loading escalated. Similarly, the findings from water solubility tests revealed a reduction in weight loss which 30.68% as fibre loading increased at 20%, indicating decreased solubility of the material. Furthermore, in soil burial tests, all samples exhibited a decrease in measured parameters as the duration of soil burial increased.

III. To produce biodegradable packaging derived from Oil Palm Leaf fiber.

This study developed a Oil Palm Leaf fiber packaging tray at the end of the discussion. The methodology of fabricating the prospective product with dimensions of 12cm x 12cm x 1cm. The method started with the physical mixing of four main ingredients: cassava starch, palm wax, glycerol, and OPLF. Following that, continue blending with the blender until the mixture is homogeneous. In this manufacturing technique, fiber content of 20% was used. The mixture was then put on a mold lined with Mylar film to facilitate removal. Following that, the mold was put in a hot press machine set to 155 ºC for 1 hour and then cooled for 20 minutes.

5.2 Recommendation for Future Research

I. To investigate an appropriate coating process for the material in order to enhance the material's moisture qualities.

II. To investigate a suitable technique for extracting Oil Palm Leaf fibre, particularly for large volume extraction.

III. To investigate an innovative material manufacturing procedure for high-volume production, such as injection moulding.

IV. To investigate a range of alternative plasticizers beyond glycerol for the biodegradable packaging such as sorbitol and urea.

5.3 Project Potential

This innovation has a strong potential for commercialization in industry as a single-use tray with minor modifications to the manufacturing process. This product has a strong potential for use as a substitute for synthetic plastic. Figure 5.1 indicates the prospective result of new material development, while Figure 5.2 represents another use of tray reinforced with OPLF, which is used to medicine, makeup, and also a drinking water. Another feature that adds value to this product is the cheap cost of the raw materials utilised. The cost calculation shown in Table 5.1 below is an approximate estimate for producing TPCS reinforced with OPLF. According to Table 5.1, the pricing is equivalent to that of other non-biodegradable bio-plastic composites at RM0.22. A study of end users, such as restaurant and grocery store owners, was undertaken to gather data on the product, and it was found that the product had the potential to be marketed in the industry

Table 5.1 Total Cost of Raw Material for one tray

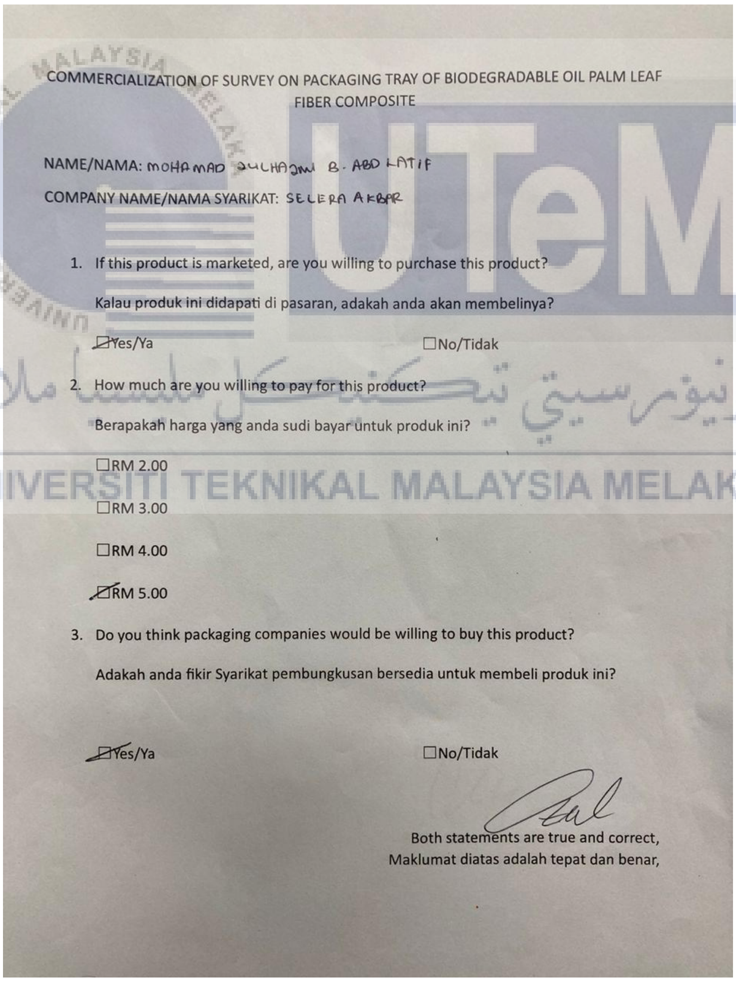
Material	Weight (g)	Price per kg (RM)	Price per gram (RM)	Price per tray (RM)
Cassava Starch	40.0	3.00	0.003	0.12
Glycerol	17.14	2.80	0.0028	0.05
Palm Wax	8.12	2.80	0.0028	0.03
Oil Palm Leaf Fibre	16.33	1.50	0.0015	0.02
Total cost				0.22

Figure 5.1 TPCS with 20% OPLF sample tray

Figure 5.2 Application of TPCS/OPLF as medicine, makeup, and drinking water tray.

Figure 5.3 shows, a survey on project potential has been done at Selera Akbar Enterprise. Encik Mohamad Zulhazmi, the owner Selera Akbar Enterprise willing to buy the packaging tray with the price RM 5.00.

Figure 5.3 Survey on potential project with the owner of Selera Akbar Enterprise



COMMERCIALIZATION OF SURVEY ON PACKAGING TRAY OF BIODEGRADABLE OIL PALM LEAF FIBER COMPOSITE

NAME/NAMA: MOHAMAD ZULHAZMI B. ABD LATIF
COMPANY NAME/NAMA SYARIKAT: SELERA AKBAR

1. If this product is marketed, are you willing to purchase this product?

   Kalau produk ini didapati di pasaran, adakah anda akan membelinya?

   ☑Yes/Ya ☐No/Tidak

2. How much are you willing to pay for this product?

   Berapakah harga yang anda sudi bayar untuk produk ini?

   ☐RM 2.00

   ☐RM 3.00

   ☐RM 4.00

   ☑RM 5.00

3. Do you think packaging companies would be willing to buy this product?

   Adakah anda fikir Syarikat pembungkusan bersedia untuk membeli produk ini?

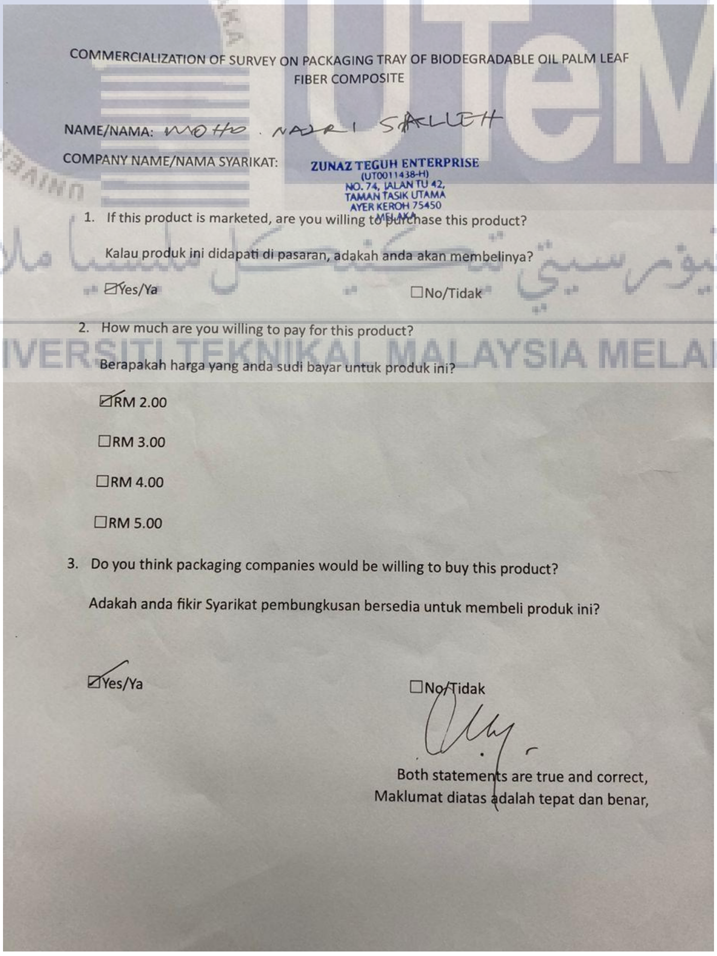
   ☑Yes/Ya ☐No/Tidak

Both statements are true and correct,
Maklumat diatas adalah tepat dan benar,

Figure 5.4 Survey question at Selera Akbar Enterprise

For figure 5.5, a survey on project potential has been done at Zunaz Teguh Enterprise. Encik Mohd Nazri Salleh also willing to but the packaging tray with the price RM2.00

Figure 5.5 Survey on potential project with Encik Mohd Nazri



COMMERCIALIZATION OF SURVEY ON PACKAGING TRAY OF BIODEGRADABLE OIL PALM LEAF FIBER COMPOSITE

NAME/NAMA: MOHD . NAZRI SALLEH

COMPANY NAME/NAMA SYARIKAT: ZUNAZ TEGUH ENTERPRISE
(UT0011438-H)
NO. 74, JALAN TU 42,
TAMAN TASIK UTAMA
AYER KEROH 75450
MELAKA

1. If this product is marketed, are you willing to purchase this product?

   Kalau produk ini didapati di pasaran, adakah anda akan membelinya?

   ☑Yes/Ya ☐No/Tidak

2. How much are you willing to pay for this product?

   Berapakah harga yang anda sudi bayar untuk produk ini?

   ☑RM 2.00
   ☐RM 3.00
   ☐RM 4.00
   ☐RM 5.00

3. Do you think packaging companies would be willing to buy this product?

   Adakah anda fikir Syarikat pembungkusan bersedia untuk membeli produk ini?

   ☑Yes/Ya ☐No/Tidak

Both statements are true and correct,
Maklumat diatas adalah tepat dan benar,

Figure 5.6 Survey question at Zunaz Teguh Enterprise

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APPENDICES

APPENDIX A GANTT CHART PSM 1

TASK / PLANNING	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Briefing PSM 1	▨								MID SEM BREAK					
CHAPTER 2: LITERATURE REVIEW														
Literature Survey		▨	▨	▨	▨	▨	▨	▨						
Chapter 2 Writing				▨	▨	▨	▨	▨						
CHAPTER 3: METHODOLOGY														
Extraction of Oil Palm Leaf Fibre										▨	▨	▨		
Chapter 3 Writing										▨	▨	▨		
CHAPTER 1: INTRODUCTION														
Chapter 1 Writing												▨	▨	
CHAPTER 4: PRELIMINARY RESULT & DISCUSSION														
Preliminaries Finding											▨			
Chapter 4 Writing											▨			
OTHERS PREPARATION														
Format Thesis														
Gantt Chart	▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	▨	▨	▨
Slide Presentation Preparation													▨	
Presentation														▨
Submit Final PSM 1 Report													▨	

APPENDIX B GANTT CHART PSM 2

TASK / PLANNING	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Receive Previous Project	■								MID SEM BREAK					
Supervisor Meeting Discussion	■	■	■	■	■	■	■	■		■	■	■	■	■
ENVIRONMENT ANALYSIS														
Water Solubility		■	■											
Soil Burial			■	■										
PHYSICAL TESTING														
Density					■	■								
WATER AFFINITY ANALYSIS														
Moisture Content						■	■							
Water Absorption						■	■							
Thickness Swelling							■	■						
PRODUCT FABRICATION														
Production of Packaging Tray										■	■			
OTHERS PREPARATION														
Report Writing	■	■	■	■	■	■	■	■		■	■	■		
Format Thesis													■	
Poster Presentation Preparation													■	
Presentation														■
Submit Final PSM 2 Report														■