UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INVESTIGATION OF PHYSICAL AND ENVIRONMENTAL BEHAVIOUR ON CORN STARCH

NUR'AIN NAZZEHA BINTI ANUAR

BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS

2022

UTeM

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical and Manufacturing Engineering Technology

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NUR’AIN NAZZEHA BINTI ANUAR

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

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2022

DECLARATION

I declare that this thesis entitled “Investigation of Physical and Environmental Behaviour on Corn Starch ” is the result of my own research except as cited in the references. This thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :
Name : Nur’Ain Nazzeha Binti Anuar
Date : 28th January 2022

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 (Process and Technology) with Honours.

Signature :
Supervisor Name : Ts. Dr. Nazri Huzaimi bin Zakaria
Date : 28th January 2022

DEDICATION

This project is dedicated to my parents, Mr. Anuar bin Haron and Mrs, Dayang Suphiani binti Abang Alli for never stop supporting me and accomodate all my needs. To my supervisor, Ts. Dr. Nazri Huzaimi bin Zakaria for guided me from the begining until the end of this project and thank you to all that involve in this project for their support and help.

ABSTRACT

The objectives of this study are to prepare and fabricate a matrix sample test from corn starch mix with plasticzer (glycerol). Then to characterize the matrix on biodegradability using soil burial testing and water solubility method. Lastly, to find the physical behaviour by using density, moisture content and water absorption testing. Composites are materials that are created by mixing two or more natural or artificial elements with various physical or chemical qualities to create a substance that is stronger as a group that as separate components. Composite materials are being invented and redesigned with the goal of improving and adapting traditional products while also introducing new products in a sustainable and appropriate way. A composite has a continuous component known as the matrix and a discrete or discontinuous component known as the fillers. Thermoplastics are polymeric materials that can be reformed (melted and hardened) repeatedly while retaining their properties. Some researchers have investigated the development and characterization of starch-based films made from cassava, sago, agar, sugar palm and many more. All these starches are potential biopolymer material for making biodegradable films. Corn is one of the most abundant sources of plant residue, offering a number of advantages such as high starch levels, outstanding uniformity, performance, ease of availability, and biodegradability. This source accounts for more than 60% of total plastic auxiliary yield. Glycerol is a valuable by-product produced in a variety of methods and by a variety of industries. Before beginning the testing, we must prepare the sample first. The sample is made of a mixture of corn starch and a plasticizer which is glycerol. For the mixture, hand mixed manually the corn starch and glycerol first before mixing using blender for two to three minutes. Then put the mixed material into the mold with the size of 140 x 60 mm, before press it in hot press machine under 25 kg/cm2 pressure. Before proceeding to hot press process, pre-heat the mold in the machine first for 15 minutes with temperature 165℃. After that, hot press the mold for 15 minutes with the same temperature then cooling process also for 15 minutes. Next, take out the sample from mold by using 10 tons press machine and the sample is ready to be cut by using cutting machine. The density of a material is an essential attribute to consider throughout the material selection process. A water absorption test is widely performed to determine how much water a material absorbs over a period of time. The equilibrium moisture content of thermoplastic was measured using moisture content. The term "water solubility" refers to a material's ability to resist water. Water solubility, in other hand, indicates how a substance degrades when immersed in water. The weight loss due to moisture and microorganism activity during the soil burial phase can be used to estimate a material's biodegradation characteristic. There are some recommendations provided to extend understanding of corn starch behaviour from this project. Suggest various type of plasticizers such as sorbitol, urea, fructose and other to investigate the behaviour and properties of corn starch. To increase the strength of thermoplastic.by adding multiple forms of plant fibers such as kenaf, banana leaf, pineapple leaf, bamboo, and others.

ABSTRAK

Objektif kajian ini adalah untuk menyediakan dan membuat ujian sampel matriks daripada campuran kanji jagung dengan plasticzer (gliserol). Kemudian untuk mencirikan matriks kebolehbiodegradasian menggunakan kaedah ujian pengebumian tanah dan kaedah keterlarutan air. Akhir sekali, untuk mencari tingkah laku fizikal dengan menggunakan ketumpatan, kandungan lembapan dan ujian penyerapan air. Komposit ialah bahan yang dicipta dengan mencampurkan dua atau lebih unsur semula jadi atau tiruan dengan pelbagai kualiti fizikal atau kimia untuk menghasilkan bahan yang lebih kuat sebagai satu kumpulan daripada komponen yang berasingan. Bahan komposit sedang dicipta dan direka bentuk semula dengan matlamat untuk menambah baik dan menyesuaikan produk tradisional sambil juga memperkenalkan produk baharu dengan cara yang mampan dan sesuai. Termoplastik ialah bahan polimer yang boleh diubahsuai (cair dan mengeras) berulang kali sambil mengekalkan sifatnya. Beberapa penyelidik telah menyiasat perkembangan dan pencirian filem berasaskan kanji yang diperbuat daripada ubi kayu, sagu, agar-agar, aren dan banyak lagi. Semua kanji ini adalah bahan biopolimer yang berpotensi untuk membuat filem terbiodegradasi. Jagung ialah salah satu sumber sisa tumbuhan yang paling banyak, menawarkan beberapa kelebihan seperti paras kanji yang tinggi, keseragaman yang luar biasa, prestasi, kemudahan ketersediaan dan kebolehbiodegradan. Sumber ini menyumbang lebih daripada 60% daripada jumlah hasil tambahan plastik. Gliserol ialah produk sampingan berharga yang dihasilkan dalam pelbagai kaedah dan oleh pelbagai industri. Sebelum memulakan ujian, kita mesti menyediakan sampel terlebih dahulu. Sampel dibuat daripada campuran kanji jagung dan pemplastis iaitu gliserol. Untuk adunan, bancuh secara manual kanji jagung dan gliserol dahulu sebelum digaul menggunakan pengisar selama dua hingga tiga minit. Kemudian masukkan bahan campuran ke dalam acuan bersaiz 140 x 60 mm, sebelum ditekan dalam mesin penekan panas di bawah tekanan 25 kg/cm2. Sebelum meneruskan proses penekan panas, panaskan dahulu acuan di dalam mesin selama 15 minit dengan suhu 165°C. Selepas itu, tekan panas acuan selama 15 minit dengan suhu yang sama kemudian proses penyejukan juga selama 15 minit. Seterusnya, keluarkan sampel daripada acuan dengan menggunakan mesin penekan 10 tan dan sampel sedia untuk dipotong menggunakan mesin pemotong. Ketumpatan bahan adalah sifat penting untuk dipertimbangkan sepanjang proses pemilihan bahan. Ujian penyerapan air dilakukan secara meluas untuk menentukan jumlah air yang diserap oleh bahan dalam satu tempoh masa. Kandungan lembapan keseimbangan termoplastik diukur menggunakan kandungan lembapan. Istilah "keterlarutan air" merujuk kepada keupayaan bahan untuk menahan air. Keterlarutan air, sebaliknya, menunjukkan bagaimana bahan merosot apabila direndam dalam air. Kehilangan berat akibat lembapan dan aktiviti mikroorganisma semasa fasa pengebumian tanah boleh digunakan untuk menganggarkan ciri biodegradasi bahan. Terdapat beberapa cadangan yang diberikan untuk memanjangkan pemahaman tentang tingkah laku kanji jagung daripada projek ini. Cadangkan pelbagai jenis pemplastis seperti sorbitol, urea, fruktosa dan lain-lain untuk menyiasat kelakuan dan sifat kanji jagung. Untuk meningkatkan kekuatan termoplastik. dengan menambah pelbagai bentuk gentian tumbuhan seperti kenaf, daun pisang, daun nanas, buluh, dan lain-lain.

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LIST OF SYMBOLS AND ABBREVIATIONS

^{o}C - Degree celcius
% - Percent
ABS - Arcrylonitrile-Butadiene_stryrene
AI_20_3 - Aluminium oxide
B4C - Boron Carbie
CMC - Ceramic matrix composite
C3H8O3 - Glycerol
HfB_2 - Hafnium diboride
Kg - Kilogram
mL - Mililiters
mm - Millimeter
MMC - Metal matrix composite
PHA - Polyhydroxy-alkanoate
PLA - Polyactic acid
PMC - Polymer matrix composite
PVC - Polyvinyl chloride
PVOH - Polyvinyl alcohol
RH - Relative humidity
SiC - Silicon Carbide
TiB2 - Titanium diboride
TPS - Thermoplastic
Wt% - Weight percent
ZrB_2 - Zirconium diboride

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CHAPTER 1

INTRODUCTION

1.1 Background

Composites are made up of two materials, one of which is called the reinforcing phase and comes in the form of fibers, papers, or particles, and the other is called the matrix phase and it is embedded in the reinforcing phase. Environmental issues have resulted in considerable interest in the development of new composite materials based in biodegradable resources. The thrust on developing innovative and weight less material from locally available, cheaper and renewable sources was of greater interest (Sathishkumar et al., 2013).

Nowadays, our world is facing problems with one of the biggest pollution which is plastic pollution. Plastic waste is a major contributor to environmental pollution because it needs thousand years to disposed. This issue is important becasue it can cause a serious damage to environment through it non-stop production and destruction. Plastic contains toxic chemical which can lead to harm effect towards air, water, earth, animals and humans (Azahari et al., 2011).

As a result, much focus has been given on the development of various biodegradable materials in order to address this serious issue (Azahari et al., 2011). Being biodegradable means that it can be degraded by the enzymatic actions of microorganisms such as bacteria, fungi, algae, and so on. So, in general, biodegradable materials are derived from natural renewable sources and starch, cellulose, lignii, chitin, protein., are the most common examples of natural biodegradable polymers (Ruhul Amin et al., 2020).

Starch is one of the most promising materials due to its availibility, economic, abundant, biodegradable, and renewable (Jumaidin et al., 2016). Starch can be the option as it is the least expensive biopolymer among the natural polymers, and starch is found in abundance in corn, potato, rice, and many other natural sources (Ruhul Amin et al., 2020). Besides starch, glycerol is one of the material that needed in producing of thermoplastic. Glycerol is a chemical that has a multitude of uses in the pharmaceutical, cosmetic, and food industries and it is also an organic compound. Glycerol is derived from natural or petrochemical feedstocks (Tan et al., 2013). However, starch-based biodegradable products reveal some disadvantages attributed mainly to starch's highly hydrophilic character (Ribba et al., 2017).

1.2 Problem Statement

These days, petroleum-based polymers have caused harm to the environment due to their production from a non-biodegradable material. This situation has to lead the world to plastic pollution. Moreover, non-biodegradable plastic also threatens food safety and quality, coastal tourism, ocean health, human health and contributes to climate change. And most visible and distressing impacts of petroleum-based plastics in marine life are suffocation, ingestion, and entanglement of hundreds of marine species (Ridhwan Jumaidin et al., 2020). Hence, a possible way to solve these issues is to produce a thermoplastic using biodegradable material. Thus, the purpose of this study is to produce biodegradable plastics that are eco-friendly and safe for the environment to replace petroleum-based plastics by using corn starch and glycerol.

1.3 Research Objective

The objectives of this study are as follows:

a) To produce the matrix by using biodegradable material which is corn starch.

b) To investigate the physical and environmental behaviour of corn starch in various plasticizer loadings.

1.4 Scope of Research

The scope of this research are as follows:

- To prepare and fabricate a matrix sample test from corn starch mix with plasticzer (glycerol).
- To characterize the matrix on biodegradability using soil burial testing and water solubility method.
- To find the physical behaviour by using density, moisture content and water absorption testing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of composite materials dates back centuries and began with natural fibers. Clay was reinforced with straw to build walls and buildings in ancient Egypt around 3000 years ago. Metals, for example, were later introduced as more durable building materials (Raj et al., 2021). Composites are materials that are created by mixing two or more natural or artificial elements with various physical or chemical qualities to create a substance that is stronger as a group that as separate components. To optimise the result of the end of the product, the component materials (matrix and reinforcement) do not mix entirely or lose their valuable qualities (Raj et al., 2021).

Composite materials, in particular, are being invented and redesigned with the goal of improving and adapting traditional products while also introducing new products in a sustainable and appropriate way. Natural fibers are mostly derived from plants or animals. The first is primarily made of cellulose, whereas the latter is made of protein. Natural fibers are commonly referred to as vegetable fibers in the composited industry. One of the problems with natural fibers is the lack of information and mechanical variances. Furthermore, the lack of industry standards for both producers and users of these materials in term of how to collect, treat, process, and post-process natural fibers adds to the selection process' complexity. These concerns are, in fact, major deterrents to the general use of natural fibers in a variety of applications. To fill this void, this study presents a study of various mechanical properties of natural fibers and their applications (Peças et al., 2018).

In addition to being environmentally friendly, composites made of biodegradable polymetric matrixes reinforced with natural fibers have remarkable mechanical properties (Beltrami et al., 2014). Biodegradability refers to the ability of microorganisms such as bacteria, fungi, algae, and others to decompose by enzymatic activity. In general, biodegradable materials are generated from natural renewable sources, such as starch, cellulose, lignin, chitin, protein, and other natural biodegradable polymers being the most common examples (Ruhul Amin et al., 2020). Figure 2.1 shows the flowchart of Biocomposite.

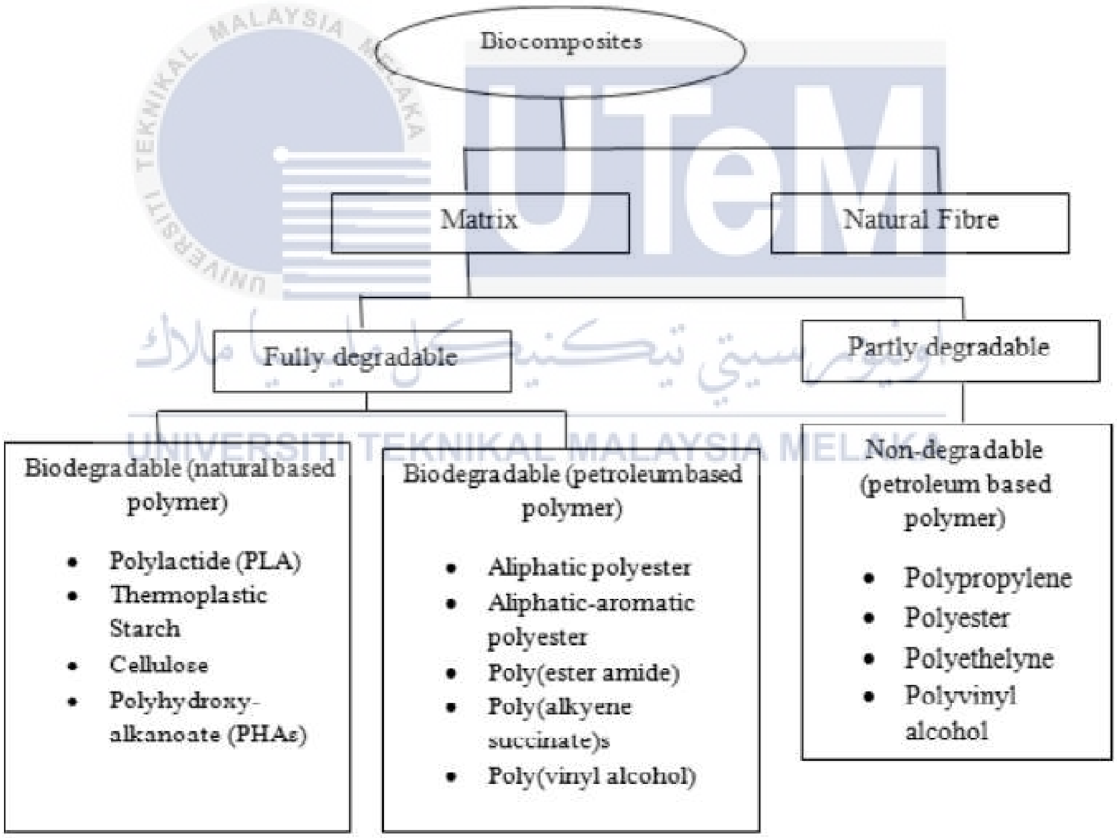


Figure 2.1 Classification of biocomposite (Sahari & Sapuan, 2012)**.**

2.2 Matrix

2.2.1 Introduction of matrix

A composite has a continuous component known as the matrix and a discrete or discontinuous component known as the fillers. The matrix and the fillers combine to form one material in the composite material. The filler is the load bearing component of the composites, while the matrix, which is the reinforcing material, holds the filler together (Ruano et al., 2016). Even though the reinforcement improves the overall characteristics of the matrix, the matrix holds the reinforcement in order to create the desire shape (Sharma et al., 2020).

2.2.2 Type of matrix

There are various types of composites. Ceramic matrix composites (CMC), polymer matrix composites (PMC), and metal matrix composites (MMC) are the type of composite (Ruano et al., 2016). The type of matrix is shown in Figure 2.2.

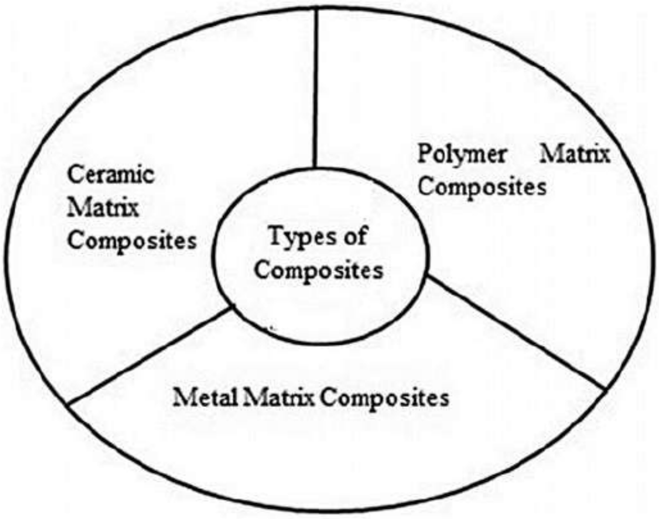


Figure 2.2 Type of matrix (Sharma et al., 2020)

Ceramic Matrix Composites (CMCs) are a mixture of ceramic particulates, fibers, and whiskers with a matrix of another ceramic and can be defined as solid materials with highly strong bonding that is typically ionic but can be covalent in a few cases. Ceramics, metals, glasses, and polymers can be used to reinforce the ceramic matrix. Ceramic-based matrix materials exhibit exceptional corrosion resistance, high melting points, superior compressive strength, and temperature stability. Ceramic matrices are a popular material for high-temperature applications such as pistons, blades, and rotors in gas turbine parts. They can withstand high temperatures and perform well in corrosive environments. The primary goals in the development of CMCs are to improve toughness because monolithic ceramics are brittle while having high stiffness and strength. It is undeniable that reinforcement, in the form of particulates and continuous fibres, has resulted in an increase in toughness, but the increase is even greater for the second, oxide-based or non-oxide-based CMCs, as illustrated by a comparison of modulus of elasticity of a few ceramics in Figure 2.3 below (Sharma et al., 2020).

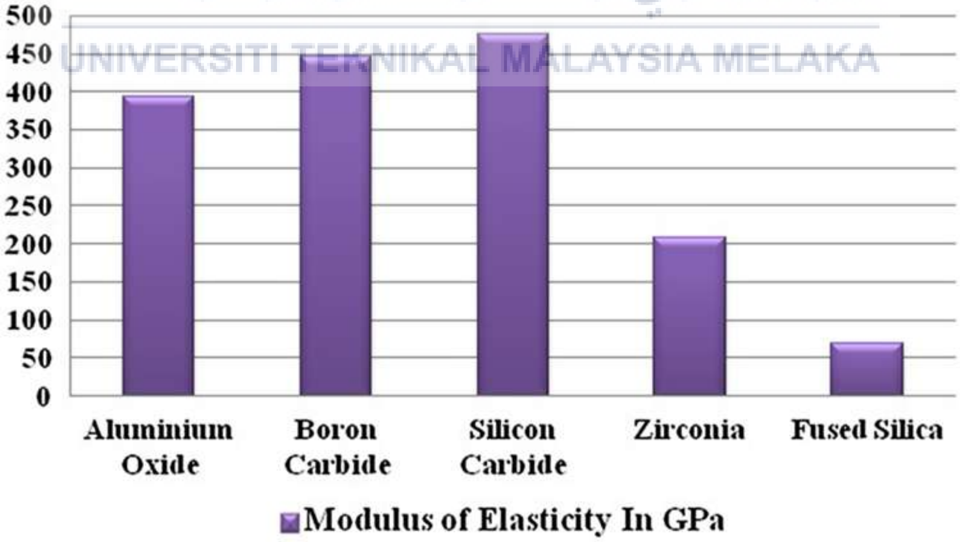


Figure 2.3 Modulus of Elasticity of ceramic materials (Sharma et al., 2020)**.**

The main disadvantage of CMCs is that they fail at low strain, which limits the stress in the fiber at lower levels. It has a relatively high modulus and lower ductility, which protects against variable thermal stresses caused by variations in thermal expansion.

Next is polymer matrix composites (PMCs). Currently, PMCs are the most commonly used composites among the available composites. The matrix in PMCs is typically reinforced with ceramic fibers due to their high strength in comparison to the matrix material. The matrix, reinforcement, process parameters, microstructure, composition, and interphase all influence the properties of PMCs. PMCs are well-known for their low cost and simple manufacturing process. PMC manufacturers can create cost-effective products using a variety of manufacturing procedures. Each manufacturing process has characteristics that define the type of product that will be produced. This knowledge enables the manufacturer to provide the best option for the consumer. Polymer matrix composites are made up of a thermoplastic or thermosetting plastic matrix and one or more reinforcement materials such as carbon, glass, steel, and natural fibres. Polymers make good components because they are easily processed. Polymers are notable for their light weight. Polymer composite composites (PMCs) have numerous properties. Some of them are high strength, excellent impact, compression, and fatigue properties; cost-effective manufacturing and tooling processes, outstanding chemical and corrosion resistance, chemical inertness at a low cost, and good mechanical characteristics. PMCs are commonly used in rockets, aircraft, and sporting equipment (Sharma et al., 2020).

This matrix performs five important functions. The first function is to keep the reinforcement phase in place. Second, under applied loads or stress, deforming and distributing stress to the reinforcement. The fibers are then bound together, transferring load to them, and providing rigidity and shape to the structure. Following that, the fibers are isolated so that individual fibers can act independently, and crack propagation is stopped or slowed. Finally, the reinforced fibers are protected from chemical attack and mechanical damage (My et al., 2017).

Metal Matrix Composites (MMCs) are widely regarded as cutting-edge materials. MMCs outperform conventional materials in terms of improved mechanical and thermal properties, including high wear resistance and exceptional thermal conductivity. The mechanical properties of some metals that are commonly used as a matrix are depicted in the Figure 2.4, Figure 2.5, Figure 2.6 below. At the moment, the most common matrix metals are aluminium, copper, iron, magnesium, nickel, and titanium (Sharma et al., 2020).

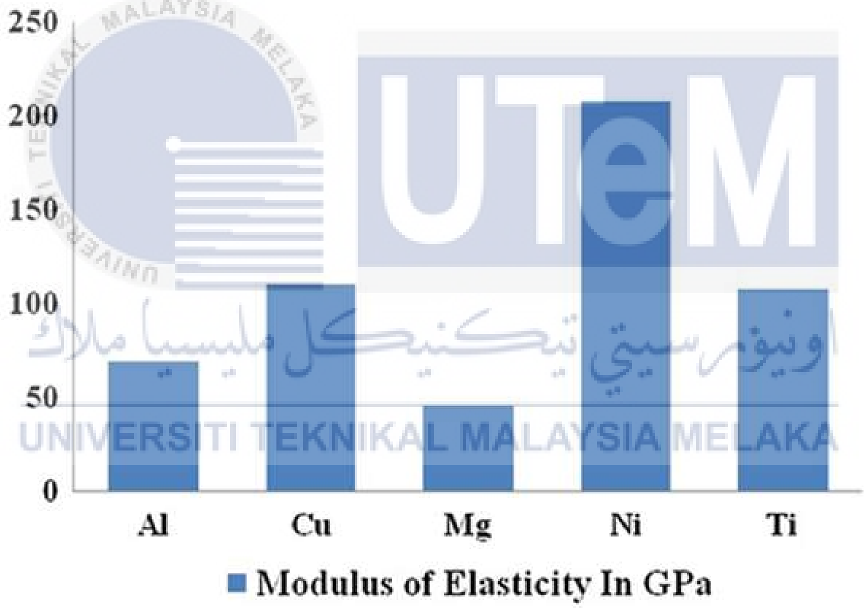


Figure 2.4 Modulus of elasicity for different metals normally used as matrix material (Sharma et al., 2020)**.**

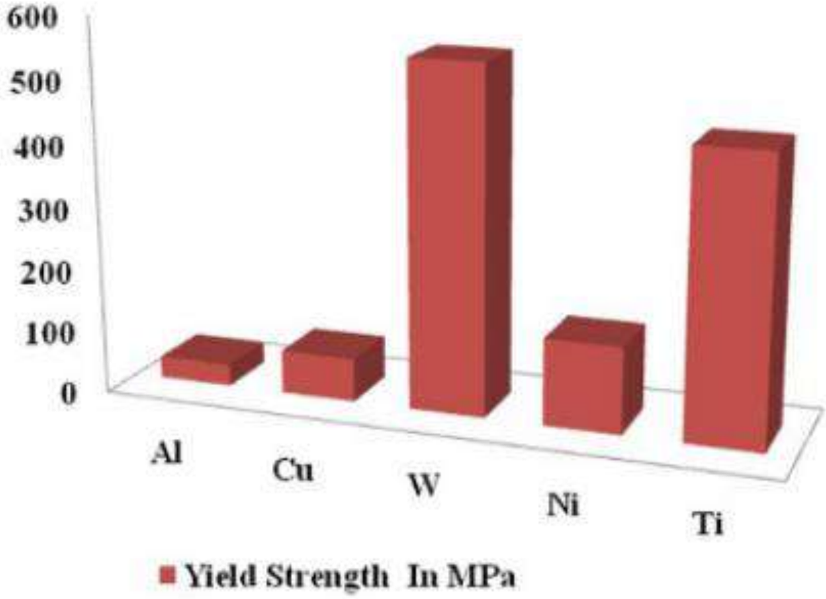


Figure 2.5 Yield Strength in Mpa (Sharma et al., 2020).

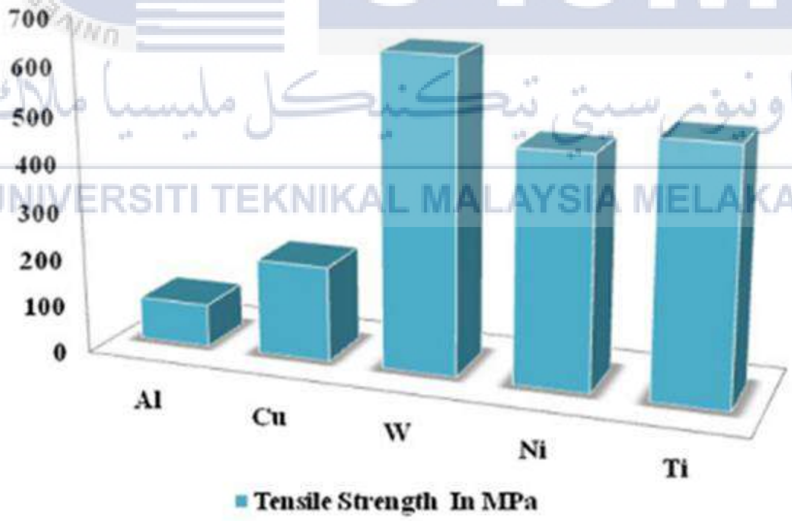


Figure 2.6 Comparison of Tensile Strength of metals commonly used as matrix material (Sharma et al., 2020)

Aluminium alloys are commonly used in structural applications in the automotive and aerospace industries due to their good forming and joining properties, low density, excellent strength, and corrosion resistance. Ceramic particles are mixed into a composite material to increase the strength of aluminium and its alloys. Titanium-based composites have numerous applications, particularly as a material for high-temperature structures. Titanium alloys are commonly used in aerospace components due to their superior high-temperature strength and corrosive resistance. The material, on the other hand, is pricey. Magnesium is the lightest of a group of nonferrous metals, and it is commonly used in electronics, chain saw housings, and gearbox housings for aerospace applications. Copper is a metal that can be easily cast and formed. Copper-based composite materials with excellent wear resistance are used in electronics as electrical contacts and system elements. Metal matrix composites have sparked a lot of interest recently for potential industrial applications. MMCs have a wide range of potential applications in a variety of industries. Recent research in the field of MMCs revealed the potential for producing composites with exceptional mechanical properties. These MMCs have the potential to be a perfect substitute for expensive conventional alloys used in structural and functional applications. For advanced structural applications, aluminium matrix composite is recommended (Sharma et al., 2020).

In order to obtain more commercially viable products, more effective fabrication methods are required; therefore, a variety of procedures are used in the manufacture of MMCs. The primary goal is to introduce additional effective, economical, and production techniques to meet the needs of various industries. A significant amount of research is being conducted in the field of MMC manufacturing, which has reduced its expenditure to a reasonable level. It is possible to achieve the desired properties for a specific application by using an appropriate combination of metal matrix and reinforcement. MMCs have metallic reinforcement properties. SiC, AI203, TinC, B4C, and TiB2 are common reinforcement particulates used to increase strength and modulus of elasticity. Among these, the incorporation of SiC and AI203 into the aluminium matrix results in improved properties (Sharma et al., 2020).

2.2.3 Biodegradable matrix

Many non-biodegradable petroleum-based polymers, such as polypropylene, polyethylene, and polystyrene, have raised several environmental problems, including waste generation, accumulation in disposal systems, and reproducibility, resulting in an increase in the volume of commercial and industrial dumps. As a result, researchers are interested in modifying existing materials to make them more environmentally friendly, as well as designing novel polymer composites from naturally occurring materials. There are numerous natural and synthetic polymers that degrade via hydrolytic (polycaprolactone, polyglycolide, plydioxanone, polylactides, polyhydroxyalkanoates) and enzymatic (polysaccharides, protein, polyaminoacids) mechanisms. Biodegradable polymers are derived from renewable resources that have been synthesised from chemicals. When exposed to environmental conditions, they are capable of decomposing. Biodegradable polymers have gotten a lot of attention because they are fully biodegradable into simple organic substances like hydrogen, carbon, and oxygen through interactions with microorganisms like algae, bacteria, and fungi (Chiellini et al., 2013).

Biodegradable polymers are classified based on their chemical composition, processing method, origin and synthesis method, application, economic importance, and so on. Because biodegradable polymers are found in nature during organism growth cycles, they are referred to as natural biodegradable polymers (Jha et al., 2019). The Figure 2.7 shows the flowchart of biodegradable polymer.

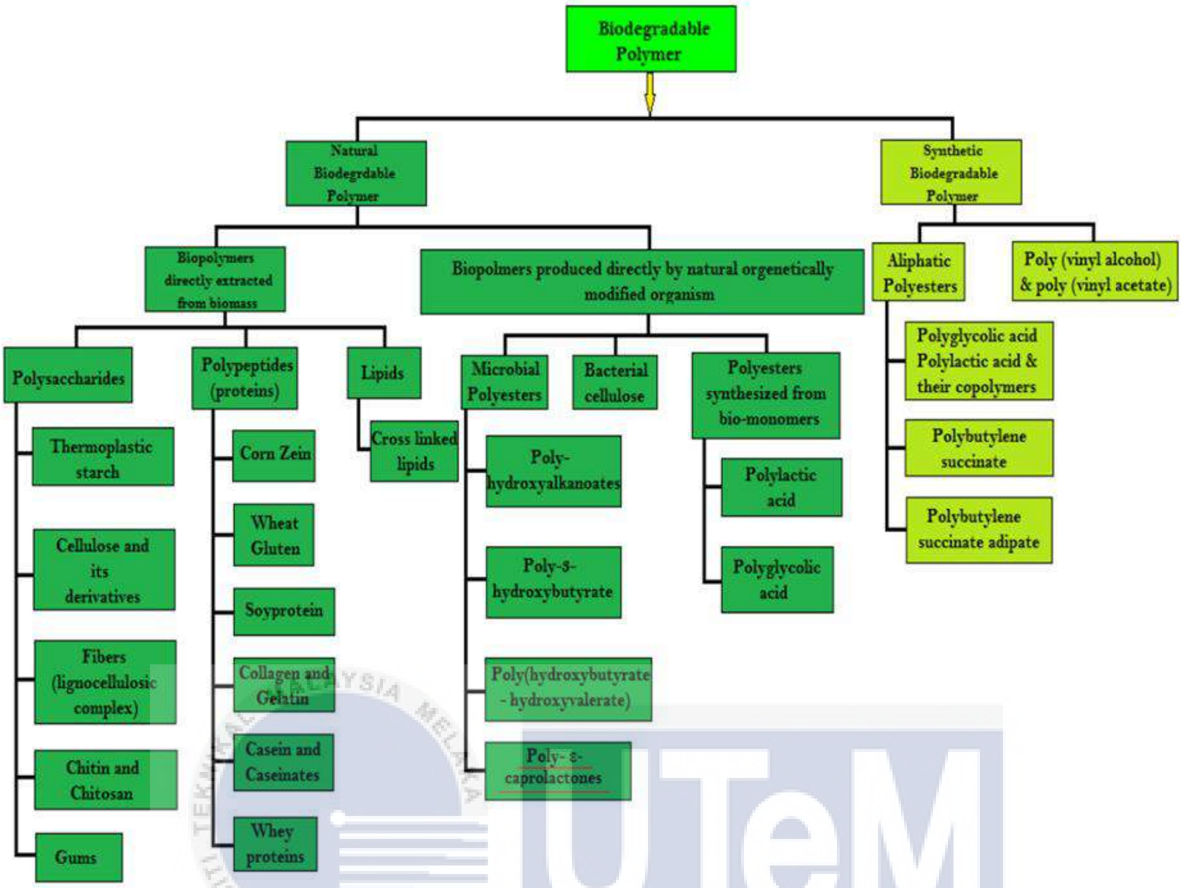


Figure 2.7 Classification of biodegradable polymers (Jha et al., 2019)

Polysaccharides are polymeric carbohydrate molecules that are made up of long chains of monosaccharide units that are joined together by glycosidic bonds. Natural occurring polysaccharides have distinct structural features in terms of molecular weight, monosaccharide composition, glycosidic linkage patterns, polysaccharide charging properties, such as solubility and rheological properties, which benefit their extensive applications in both food and non-food areas. Because most polysaccharides perform their functions in aqueous solution, understanding polysaccharide solubility is critical. This chapter specifically addressed the molecular mechanisms of polysaccharide solubility. It was discovered that there are relationships between polysaccharide solubility and molecular structures. It should also be noted that the current chapter only addressed polysaccharides in aqueous solution; the solubility of polysaccharides in other organic solvents was not addressed (Guo et al., 2017).

Thermoplastics are polymeric materials that can be reformed (melted and hardened) repeatedly while retaining their properties. This makes the material recyclable, which, in addition to being renewable and biodegradable, adds to its positive attributes (Jumaidin et al., 2019). Thermoplastic starch is created by disrupting the starch granule structure through the use of low water content starch and thermal and mechanical forces in the presence of a plasticizer (Ruhul Amin et al., 2020). Table 2.1 below shows the typical characteristics and applications of some thermoplastics.

Table 2.1 Typical characteristics and applications of some thermoplastics (Yashas Gowda et al., 2018)**.**

Thermoplastics	Characteristics	Applications
Acrylics	Exceptional long-term exposure to sunlight and good light transmission.	Swimming pools, skylights, sinks and wash basins and on tail lights on automobiles.
Acrylonitrile-Butadiene-Styrene (ABS)	Outstanding impact strength and high mechanical strength.	Automotive parts, electrical and electronic applications, and packaging.
Polycarbonate	Excellent electrical insulating characteristics, strong, and rigid.	Packaging films, house wares, toys, containers, pipes, gasoline tanks, and coatings.
Polypropylene	Light-weight material and good insulation properties.	Packaging and foodservice products, automotive parts, radio and TV housing.
Polyamide-Imide	Exceptional mechanical, thermal and chemical resistance properties	Aerospace, heavy equipment and automotive

2.2.4 Advantages and disadvantages

The matrices have their own benefits and limitations. These are some of advantages that I have found in some journals. For polymer matrix, epoxy resin is usually recognized for advanced composites because of its properties such as good stiffness, corrosion, dimensional stability, and chemical resistance also good in thermal properties (Muhammad & Ahmad, 2013). Next, one of the benefits for ceramic matrix is that the heat shield system of space vehicles is exposed to temperatures above 1500°C for a few minutes during the re-entry phase. Only ceramic materials can withstand such conditions without significant damage, and only CMCs can hold up thermal shocks adequately. The development of CMC-based heat shield systems promises the following benefits: reduced weight, increased system load carrying capacity, reusability for multiple re-entries, and better steering during the re-entry phase with CMC flap systems (Basutkar & Kolekar, 2020).

For the polymer matrix, this kind of matrix serves as the binding material in the preparation of polymer composites (binder). It aids in the retention of fillers as well as the transmission of stress within the material. As a result, if the interfacial interaction is poor, the transmission of an externally applied stress will be poor, resulting in material failures (Ruano et al., 2016). Next, the limitations of metal matrix are the techniques of its fabrication can only be used with discontinuous reinforcements, also the costs are high, and the products are limited to the simple shapes that obtained by extrusion, rolling or forging. This is caused by complicated manufacturing processes of metal matrix (Haghshenas, 2016).

2.2.5 Examples of matrix

The example matrix for polymer matrix composites (PMCs) is epoxy, polyester and phenolic. Meanwhile for metal matrix composites (MMCs) is aluminium, titanium, and magnesium. Lastly, SiC, carbon, ZrB_2, HfB_2, Al_2O_3 is the example of matrix for ceramic matrix composites (CMCs). The examples of matrix are shown in Figure 2.8 below.

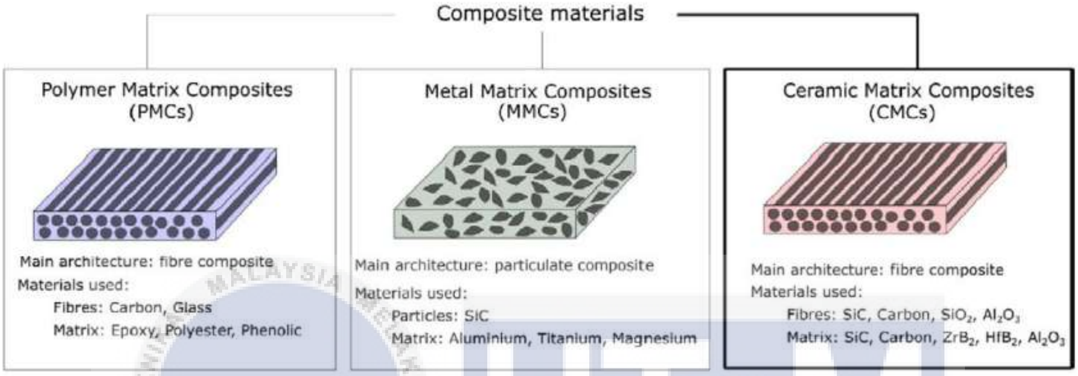


Figure 2.8 Classification of the composite materials depending on the nature of the matrix showing for each of them the main reinforcing architectures and materials used (Gavalda Diaz et al., 2019).

2.3 Starch

2.3.1 Introduction of starch

As a common polysaccharide, starch is a polymer made up of high number of saccharide molecules with the potential to be used as a biodegradable plastic (Abdullah et al., 2018). The two primary components of starch, amylose and amylopectin, have a significant impact on the physicochemical and functional qualities (Mir et al., 2017). Amylopectin is a highly branching structure of short -1,4 chains joined by -1,6 bonds, whereas amylose is a linear structure of -1,4 linked glucose units (Jumaidin et al., 2017).

Regardless of plant origins, amylose is a starch made up of two different forms of any anhydroglucose polymers. The macromolecules amylose and amylopectin, which represent for 98-99 percent of the dry weight, are referred to as amylose and amylopectin. When dissolved, amylose has a tendency to form insoluble semicrystalline aggregates due to its low degree of branching. In the production of such insoluble semicrystalline aggregates, the position of the branches in the amylose structure is also important. The next main component of starches is amylopectin, which is made up of a huge number of shorter chains with a lot of branches. Unlike linear amylose, which is primarily amorphous or semicrystalline, amylopectin has crystalline regions that render it insoluble even in hot water. Basically, the length of the amylopectin chain is thought to be the most important element in crystalline polymorphism. However, it's worth nothing that amylopectin's short-branched chains are the predominant crystalline component of native starch granules, whilst amylose and amylopectin's branching chain create amorphous regions. The partial crystallinity of natural starch granules is thus due to an structure of amylopectin side chains aggregated together. The amylose and amylopectin ratio of the starch is determined by its source, age, and the extraction procedure used (Jawaid & Swain, 2017). The starch structure of amylose and amylopectin are shown in Figure 2.9 and Figure 2.10. Meanwhile the segment for amylose and amylopectin molecule are shown in Figure 2.11 and Figure 2.12.

Figure 2.9 Starch amylose structure (Jawaid & Swain, 2017)**.**

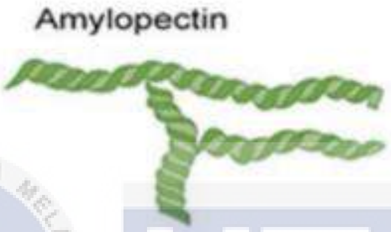


Figure 2.10 Starch amylopectin stucture (Jawaid & Swain, 2017)**.**

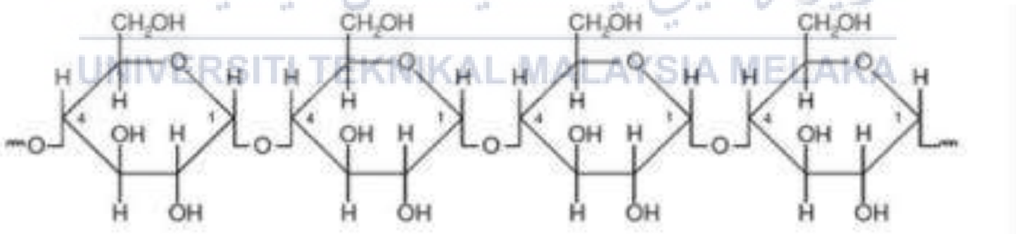


Figure 2.11 Segment of amylose molecule (Pérez-Pacheco et al., 2016)**.**

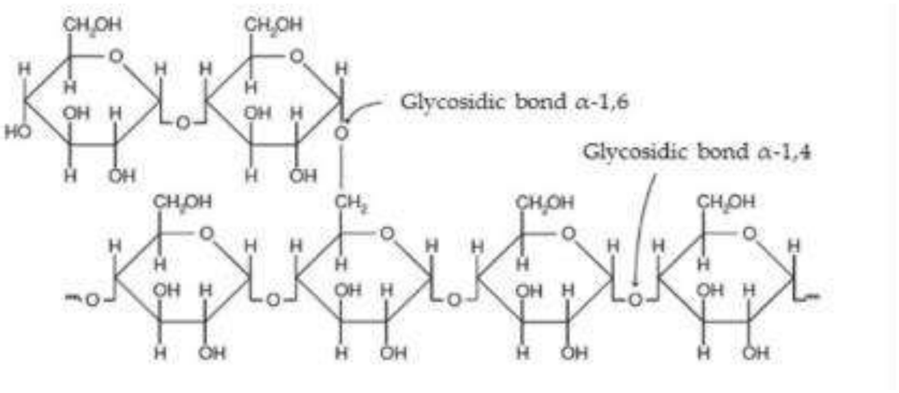


Figure 2.12 Segment of amylopectin molecule (Pérez-Pacheco et al., 2016)

However, other appealing properties of this material, like as its natural availability, biodegradability, low cost, and convenience of applying it to chemical modifications, have led to a variety of other uses (Guimarães et al., 2010). Starch is the least cost biopolymer among natural polymers, and it can be found in abundance in corn, potato, rice, and a variety of other natural sources. As a result, since the 1970s, starch has been employed in the plastic industry to create biodegradable plastic materials (Ruhul Amin et al., 2020). The basic structure of the starch molecule is shown in Figure 2.13.

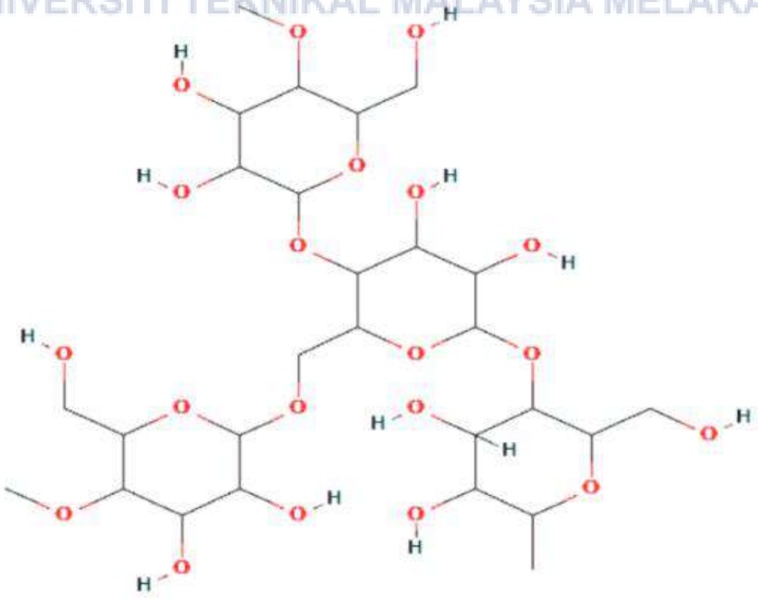


Figure 2.13 Basic structure of the starch molecule (Palanisamy et al., 2020)

2.3.2 Type of starch

The starch has generated a lot of interest as a potential packaging alternative to typical plastics. Some researchers have investigated the development and characterization of starch-based films made from cassava, sago, agar, sugar palm and many more. All these starches are potential biopolymer material for making biodegradable films (Sanyang et al., 2015).

Compared to other types of starch, cassava starch, also known as Manihot esculenta, contributes the most to productivity yield. Cassava is expected to have a yield potential of up to 17,000 kg of starch per hectare per year if maintained in a suitable location using organized farming technique (Ridhwan Jumaidin et al., 2020).

The Arenga Pinnata or usually known as sugar palm is a multipurpose tree that could be found in almost every tropical country. Almost every part of the tree is used to make local products like ropes, brushes, brooms, mats, cushions, palm wine, neera syrup, vinegar, and many others (Ilyas et al., 2019).

Sago palm (Metroxylone sagu) is a tropical South East Asian plant that is native to Malaysia, Indonesia, Papua New Guinea and Thailand. It has been an essential source of carbohydrate for the native population since prehistoric times. The sago palm is the starch-producing crop with the largest production, with up to 25 tonnes of starch per hectare each year. In term of yield per unit area, it could be three to four times higher than rice, corn, or wheat, and 17 times higher than cassava (Azmi et al., 2017). Table 2.2 shows the concentration of various starch sources of amylose and amylopectin.

Table 2.2 Amylose and amylopectin concentration of various starch sources
(Marichelvam et al., 2019).

Source	Amylose (in %)	Amylopectin (in %)
Arrowroot	20.5	79.5
Banana	17	83
Cassava	18.6	81.4
Corn	28	72
Potato	17.8	82.2
Rice	35	65
Tapioca	16.7	83.3
Wheat	20	80

2.3.3 Corn starch

Corn is one of the most abundant sources of plant residue, offering a number of advantages such as high starch levels, outstanding uniformity, performance, ease of availability, and biodegradability (Hazrol et al., 2021). Corn starch contributes for about 80 percent of the world's starch market. This starch is an important ingredient in the foodservice industry because of its excellent phycochemical and techno-functional characteristics, and it is commonly used as a thickener, stabilizer, textural modifier, gelling, bulking, and water retention agent in food formulations (Mir et al., 2017).

A little amount of protein (0.35 percent), fat (0.8 percent), ash, and >98 percent of two polysaccharides, which is amylose and amylopectin, are discovered in basic corn starches. Corn and waxy maize starch granules usually range in size from 2 to 3 mm, with the majority occurring between 12 and 15 mm. They also differ in shape, appearing as polygon cross-sections (Palanisamy et al., 2020). Table 2.3 below shows the physical and chemical properties of corn starch.

Table 2.3 Physical and chemical properties of corn starch (Marichelvam et al., 2019)**.**

Properties	**Corn starch**
Moisture content (in %)	10.82
Ash content (in %)	0.32
Protein (in %)	0.38
Fat (in %)	0.32
Fiber (in %)	0.10
Amylose (in %)	29.4
Density (g/ml)	1.356
pH	6.72

2.3.4 Advantages and disadvantages

One of the advantages of starch is that, after cellulose, it is regarded as the second most important renewable resources. It is both affordable and totally biodegradable, which has generated a lot of interest in using it as a bioplastic component. Starch is a versatile material since it can be transformed into chemicals like ethanol, acetone, and organic acids utilised in synthetic polymer manufacturing, such as polylactic acid (PLA), as well as thermoplastic (TPS) with the help of a plasticizer at shear temperature conditions. Then, the colour of pure starch is white. It’s a tasteless, odourless powder that’s one of the most common natural polysaccharides synthesized from plants, with global starch output exceeding 50 million tonnes per year (Diyana, Jumaidin, Selamat, Ghazali, et al., 2021).

Meanwhile, due to some limitations, biodegradable polymer cannot be used in a wide range of applications. When compared to typical thermoplastics, starch-based biodegradable products reveal some disadvantages, which can be related to starch's highly hydrophilic characteristic. Strong hydrogen bonds normally hold the starch chains together, leading starch granules to be insoluble in cold water. When starch is turned into thermoplastic, the crystalline structure is damaged, allowing water molecules to interact with hydroxyl groups and producing partial solubilization of the starch granules. Because of starch's hydrophilic nature, it has a low water stability and a high moisture sensitivity, limiting the development of starch-based materials (Ridhwan Jumaidin et al., 2017).

2.4 Plasticizer

2.4.1 Introduction of plasticizer

Plasticizers are one of the most important additives required in the processing of polymer materials, especially polyvinyl chloride (PVC) plastics. This source accounts for more than 60% of total plastic auxiliary yield. Traditional petroleum-based phthalate plasticizers used to account for a large portion of total plasticizer production and sales, but they have gradually been phased out due to potential health and environmental risks. Green plasticizers that are non-toxic and have excellent performance, oil resistance, extraction, and migration resistance are constantly being developed, manufactured, and used in electrical insulation, food packaging, and medical and health products. Plasticizers are functional additives that improve the flexibility, plasticity, processability, and elongation of polymers, most notably in PVC products. Plasticizers are most commonly used to increase polymer flexibility and elongation while decreasing hardness, softening temperature, elastic modulus, and embrittlement temperature. Non-phthalate plasticizers include citric acid ester, phosphates, polyesters, halogenated alkanes, and epoxy compounds. Global hygienic requirements for plastic additives are increasing as people become more aware of environmental protection issues, particularly the discovery of potential risks to human health posed by phthalate plasticizers and ecological pollution issues (Jia et al., 2018).

2.4.2 Type of plasticizer

Plasticization can be categorized into two techniques which are external and internal. External plasticization is a physical mixing procedure that provides plasticity. External plasticizers are not chemically bonded to the polymer. Therefore, they can evaporate, migrate, or extrude from polymer products. Internal plasticization is the process of incorporating comonomers into polymers or reacting with them to create flexible chain units. Internal plasticizers are the group (flexible segment) that are part of a basic polymer chain and can be grafted as side chains or integrated regularly or irregularly between inflexible monomers (hard segments) to reduce intermolecular forces (Wojciechowska, 2012).

Plasticizers are classified as primary or secondary based on their solubility in highly concentrated polymers. It is referred to as a plasticizer if it is soluble and capable of fast gelling the polymer at standard processing temperature. Secondary plasticizers, on the other hand, have lower gelation capabilities and are typically combined with main plasticizers to improve product qualities or reduce cost (Nur Hanani et al., 2013).

The most typical plasticizer used for starch-based films are polyols such as sorbitol and glycerol, amongst many others. Several studies have been carried out to identify how polyols (particularly glycerol and sorbitol) affect the characteristics of films made from several starch origins (Sanyang et al., 2015). To create a deformable thermoplastic material called Thermoplastic starch, a plasticizer such as urea, glycerol, sorbitol, glycerin, and water is required (TPS) (Khan et al., 2017).

2.4.3 Glycerol

Glycerol is a valuable by-product produced in a variety of methods and by a variety of industries. Glycerol, also called glycerine or propane-1,2,3-triol, is a chemical with a wide range of applications in the pharmaceutical, cosmetics, and food industries.

Glycerol is some kind of organic substance with the formula $C_3H_8O_3$. Glycerine. Propane-1,2,3-triol, 1,2,3-propanetril, 1,2,3-trihydroxypropane, glyceritol, and glycyl alcohol are all synonyms for it. Glycerol is a low-toxicity alcohol made composed of three carbon chains, each having a hydroxyl group attached. It is derived from natural or petrochemical feedstocks. Glycerol is virtually non-toxic to humans and the environment. Glycerol is a liquid that is transparent, colourless, odourless, hygroscopic, vicious, and tasted sweet (Tan et al., 2013). Figure 2.14 shows the chemical structure of glycerol.

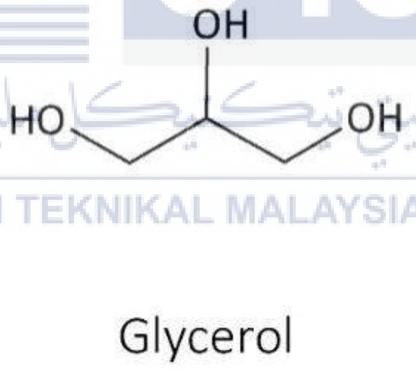


Figure 2.14 Chemical structure of Glycerol (González et al., 2020)

2.4.4 Advantages and disadvantages

The benefits of plasticizer include improved workability and reduced film brittleness when added to pure starch. Furthermore, when multiple plasticizers are used in a film matrix, strong interactions between the plasticizers can occur (plasticizer-plasticizer interactions), which can improve certain functional properties of the film (Sanyang et al., 2015). This latter option refers to the development of natural-based plasticizers, which has recently sparked interest in academic and industrial research. The use of such plasticizers, which are low in toxicity and have good compatibility with a variety of plastics, resins, rubber, and elastomers, to replace conventional synthetic plasticizers is becoming more appealing (Hazrati et al., 2021). Aside from that, the plasticizer should be natural, inexpensive, and renewable in order to make the process both cost effective and biodegradable (Khan et al., 2017). The benefits of using a plasticizer include increased elongation, softness, solvency, surface lubricity, decreased viscosity, improved thermal stability, and flexibility (Hazrol et al., 2021).

However, plasticizers have their own limitations, such as the formation of discontinuity zones during film dying due to phase separation caused by water insoluble plasticizers. As a result, the rates of water vapour permeability increase. An optimum stirring rate of the polymetric dispersion with the plasticizer can achieve complete uptake of the insoluble plasticizer by the polymer (Vieira et al., 2011).

2.5 Previous result

2.5.1 Moisture content and water solubility testing

Based on study by Ibrahim et al., (2019), the result for moisture content and water solubility testing were regardless of plasticizer type, increasing the plasticizer concentration from 25% to 40%, then to 55%, increases the water retention of plasticized films that rely on the plasticizers' ability to hold water. The effect of urea on the moisture content of corn starch films, on the other hand, was more prevalent than that of fructose and sorbitol-plasticized films. The difference in water retention of plasticized films was attributed to the resemblance of glucose units in the plasticizers' molecular structure, with the lower resemblance of glucose units causing a weak molecular interaction between the plasticizer and the intermolecular of biopolymer chains. As a result, the plasticizer's ability to interact with water molecules increased. The water solubility of the starch-based film is an important feature property for applications that may require water insolubility to improve water resistance and product integrity. As a result of the plasticizers' hydrophilic nature, both the type and concentration of plasticizer had a strong influence on the water solubility of corn starch films. The addition of plasticizers reduces interactions between polymer molecules, resulting in more free space in the structure of the polymer chain. This, in turn, allows water fragments to penetrate the film matrix, maximizing plasticized film solubility (Ibrahim et al., 2019).

2.5.2 Soil burial testing

Next is soil burial testing. The result is based on a previous study by Azahari et al., (2011). Figure 2.15 and Figure 2.16 show the weight loss of pure PVOH and PVOH/CS, respectively. Soil and compost films, respectively. According to the figures, as the burial time increased in both the soil and compost for eight weeks, the biodegradability increased up to 85 percent. In the first seven days, all of the films in the soil and compost degraded rapidly. This rapid degradation was caused by the composting process, which consisted of two major stages: active composting and curing. The temperature rose and remained elevated in the first stage as long as there was available oxygen, resulting in intense microbial activity. The weight loss of PVOH/CS films after eight weeks in the soil is shown in figure Figure 2.15.

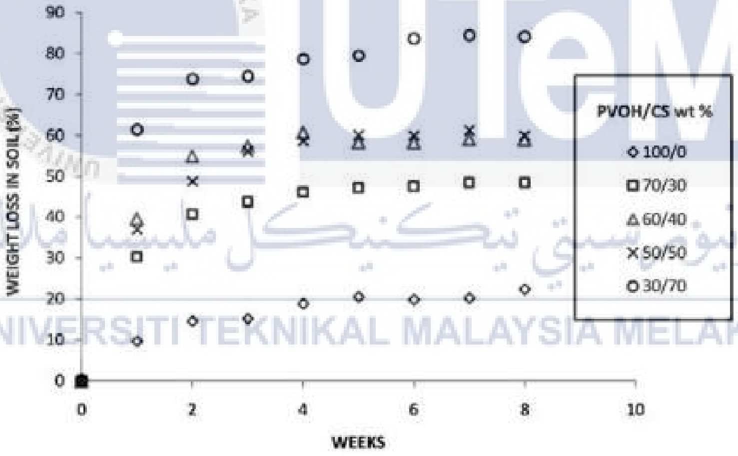


Figure 2.15 Weight loss of PVOH/CS films after eight weeks in soil (Azahari et al., 2011)

The temperature dropped in the second stage, but the film continued to compost at a slower rate. The 30/70 PVOH/CS sample showed the most significant weight loss in both soil and compost, while pure PVOH showed the most minor weight loss over time. This finding was attributed to the film's corn starch content, which is more biodegradable than pure PVOH. Because of its high hydrolysability, PVOH is biodegradable and has a higher resistance to soil burial degradation. The addition of compost increased the degradation rate by approximately 2–3 percent. Compost is made up of organic materials derived from decomposed plant and animal matter.

Aerobic decomposition was used to decompose the majority of the material. It may be nutrient-dense. The compost itself is beneficial to the land in a variety of ways, as it can act as a soil conditioner, a fertiliser, a source of vital humus or humic acids, and a natural pesticide for the soil. The nutrients in compost can degrade the film faster than unaltered soil.

As shown in Figure 2.16, the weight loss was slightly lower for the duration of 14 to 30 days, but the composting process did not come to a halt at any point. Instead, it proceeded slowly until the last remaining nutrients were consumed by the remaining microorganisms and nearly all of the carbon was converted to carbon dioxide. For the result of weight loss of PVOH/CS films after eight weeks in the compost is shown in Figure 2.16 below.

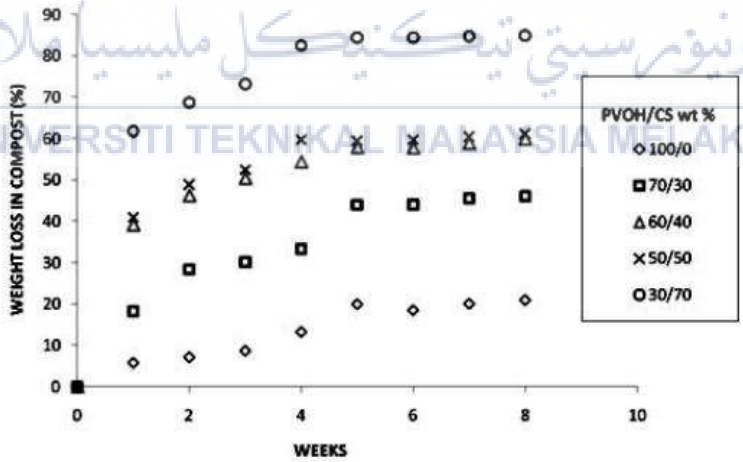
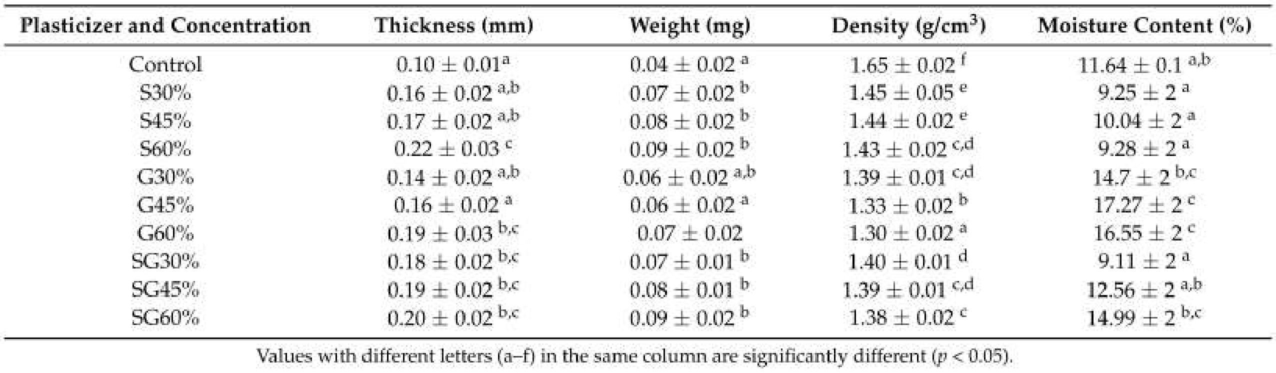


Figure 2.16 Weight loss of PVOH/CS films after eight weeks in the compost (Azahari et al., 2011)

2.5.3 Density testing

For density testing, the result is based on (Hazrol et al., 2021), according to table in Figure 2.17, adding plasticizers reduced the density of corn starch from 1.65 g/cm3 to 0.65 g/cm3. As a result, the plasticized corn starch films were less dense than the unplasticized corn starch film. Table in Figure 2.17 shows the effect of plasticizer types and concentrations on the density of corn starch films. Raising the plasticizer concentration from 30% to 60% resulted in slight decreases in the density of S- (1.45–1.43 g/cm3), G- (1.39–1.30 g/cm3), and SG-plasticized films (1.40–1.38 g/cm3). It can be demonstrated that increasing the percentage of plasticizers from 30% to 60% reduced film density marginally regardless of plasticizer type. The plasticized films S, G, and SG produced results that were consistent with those obtained from Hazrol et al., (2021), a dry treatment technique (hot pressing) is used to plasticize sugar palm starch with glycerol (15, 30, and 45 percent). The density values revealed no distinction between the various types of plasticizers. However, in decreasing order of density, S, SG, and G plasticized films with the same plasticizer concentration are used. This phenomenon could explain the difference in molecular weight and density of plasticizers. In the Figure 2.17 below shows the table of physical properties of corn starch films incorporated with various plasticizer types and concentration.



Plasticizer and Concentration	Thickness (mm)	Weight (mg)	Density (g/cm^3)	Moisture Content (%)
Control	0.10 ± 0.01^{a}	0.04 ± 0.02^{a}	1.65 ± 0.02^{f}	$11.64 \pm 0.1^{a,b}$
S30%	$0.16 \pm 0.02^{a,b}$	0.07 ± 0.02^{b}	1.45 ± 0.05^{e}	9.25 ± 2^{a}
S45%	$0.17 \pm 0.02^{a,b}$	0.08 ± 0.02^{b}	1.44 ± 0.02^{e}	10.04 ± 2^{a}
S60%	0.22 ± 0.03^{c}	0.09 ± 0.02^{b}	$1.43 \pm 0.02^{c,d}$	9.28 ± 2^{a}
G30%	$0.14 \pm 0.02^{a,b}$	$0.06 \pm 0.02^{a,b}$	$1.39 \pm 0.01^{c,d}$	$14.7 \pm 2^{b,c}$
G45%	0.16 ± 0.02^{a}	0.06 ± 0.02^{a}	1.33 ± 0.02^{b}	17.27 ± 2^{c}
G60%	$0.19 \pm 0.03^{b,c}$	0.07 ± 0.02	1.30 ± 0.02^{a}	16.55 ± 2^{c}
SG30%	$0.18 \pm 0.02^{b,c}$	0.07 ± 0.01^{b}	1.40 ± 0.01^{d}	9.11 ± 2^{a}
SG45%	$0.19 \pm 0.02^{b,c}$	0.08 ± 0.01^{b}	$1.39 \pm 0.01^{c,d}$	$12.56 \pm 2^{a,b}$
SG60%	$0.20 \pm 0.02^{b,c}$	0.09 ± 0.02^{b}	1.38 ± 0.02^{c}	$14.99 \pm 2^{b,c}$

Values with different letters (a–f) in the same column are significantly different ($p < 0.05$).

Figure 2.17 The table of physical properties of corn starch films incorporated with various plasticizer types and concentration (Hazrol et al., 2021)**.**

2.5.4 Water absorption testing

For water absorption testing, Figure 2.18, Figure 2.19, and Figure 2.20 show the percentage of weight gain for the corn starch-plasticized film based on water intake. Water absorption is important for starch films because it acts as a plasticizer. Plasticized films with a higher plasticizer and moisture content were more flexible. The immersion time was limited to 160 minutes because the film samples began to dissolve in water at 140 minutes due to the high hydrophilicity of plasticized films with higher plasticizer content. The formation of hydrogen bonds with starch caused by the presence of hydroxyl groups within the plasticizer molecules resulted in a higher tendency of water absorption into plasticized polymers.

Figure 2.18, Figure 2.19, and Figure 2.20 show the water absorption percentage as a function of time for corn starch films with various types of plasticizer and material. Surprisingly, both films absorbed a large volume of water at room temperature during the first 20 minutes of immersion. Because of their water-soluble and naturally hygroscopic properties, higher plasticizer content improved the films' water absorption. The control film absorbed approximately 120 percent in 40 minutes, whereas the S-, G-, and SG-plasticized films absorbed approximately 147 percent, 112 percent, and 135 percent of the plasticized films, respectively. Except for the 60 percent glycerol-plasticized film, the control film and all films with different plasticizer types and content began to dissolve in water after 140 minutes. For the result, it is shown in Figure 2.18, Figure 2.19 and Figure 2.20.

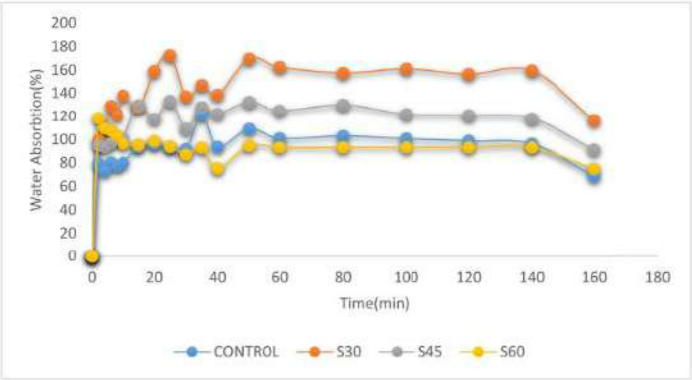


Figure 2.18 Water absorption on corn starch films with sorbitol plasticizer (Hazrol et al., 2021).

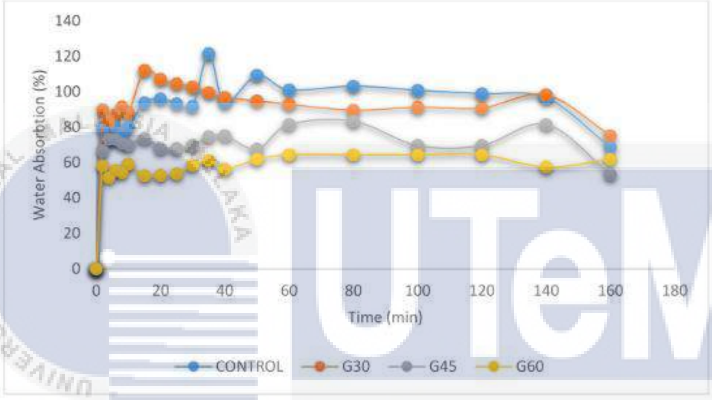


Figure 2.19 Water absorption on corn starch films with glycerol plasticizer (Hazrol et al., 2021)**.**

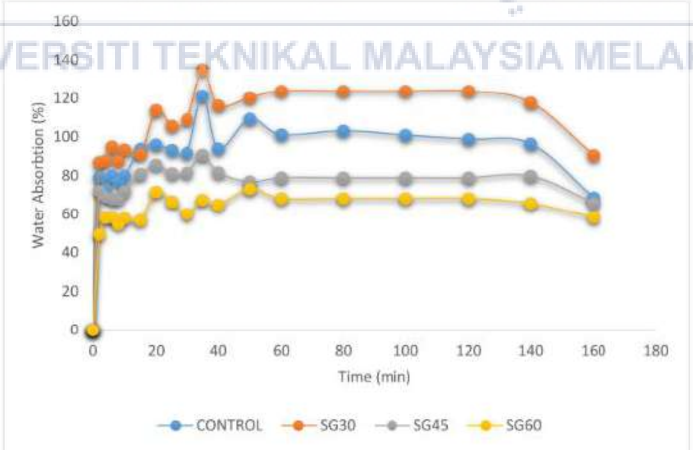


Figure 2.20 Water absorption on corn starch films with sorbitol/glycerol plasticizer (Hazrol et al., 2021)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter introduces the methodology that has been discussed, and it will be carrying out in this project development as planned. This chapter includes the processes based on the scope of this project, the flow charts of the process to make sure that this project will be done on time in order to complete this project. The methods that will be used in this project is physical method which are moisture content, density and water absorption testing and environmental method which are soil burial testing and water solubility.

3.2 Flow chart

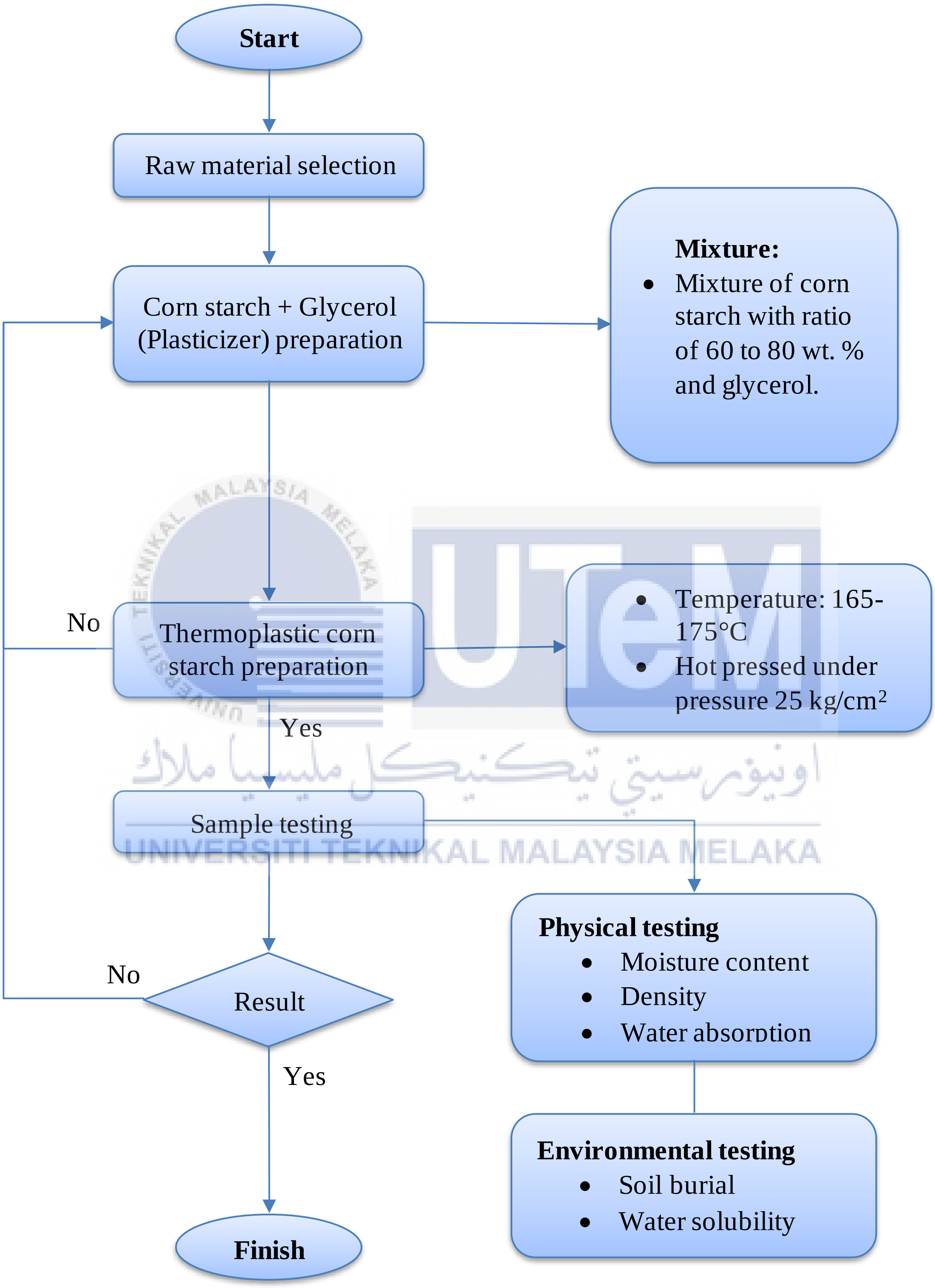


Figure 3.1 Flow chart of the process

3.3 Raw material

The natural material that has been choose for this study is corn starch, due to its unique functional properties, lack of odour, low cost, and quality, corn starch is widely used in processed foods, pharmaceuticals, textiles and paper products among others (Abotbina et al., 2020). The corn starch were purchased from Polyscientific Enterprise Sdn. Bhd. Then, the next material that need to prepare for fabricate the matrix sample is plasticizer, which is glycerol. The glycerol was produced by Qrec Chemicals, also purchased from the same supplier as the corn starch.

Figure 3.2 Corn starch

Figure 3.3 Glycerol

Table 3.1 Glycerol material specification

Specification	**Composition**
Assay (acidimetric)	Min. 99.5%
Insoluble in water	Passes test
Acidty/alkalinity	Passes test
Halogen Compounds (as Cl)	Max. 0.003%
Chloride (Cl)	Max. 0.001%
Sulfates (SO_4)	Max. 0.001%
Ammonium (NH_4)	Max. 0.0015%
Arsenic (As)	Max. 0.0001%
Copper (Cu)	Max. 0.001%
Heavy Metals (as Pb)	Max. 0.0005%
Iron (Fe)	Max. 0.0005%
Lead (Pb)	Max. 0.001%
Nickle (Ni)	Max. 0.0005%
Zinc (Zn)	Max. 0.001%
Aldehydes (HCHO)	Max. 0.0005%
1,2,4-butantriol (G.C)	Max. 0.2%
Sulfated Ash	Max. 0.01%
Water	Max. 2%

3.4 Material preparation

Before beginning the testing, we must prepare the sample first. The sample is made of a mixture of corn starch and a plasticizer which is glycerol. For the mixture, hand mixed manually the corn starch and glycerol first before mixing using blender for two to three minutes. Then put the mixed material into the mold with the size of 140 x 60 mm, before press it in hot press machine under 25 kg/cm^2 pressure. Before proceeding to hot press process, pre-heat the mold in the machine first for 15 minutes with temperature 165°C. After that, hot press the mold for 15 minutes with the same temperature then cooling process also for 15 minutes. Next, take out the sample from mold by using 10 tons press machine and the sample is ready to be cut by using cutting machine.

Figure 3.4 Mild Steel Mould

Figure 3.5 Mould Description

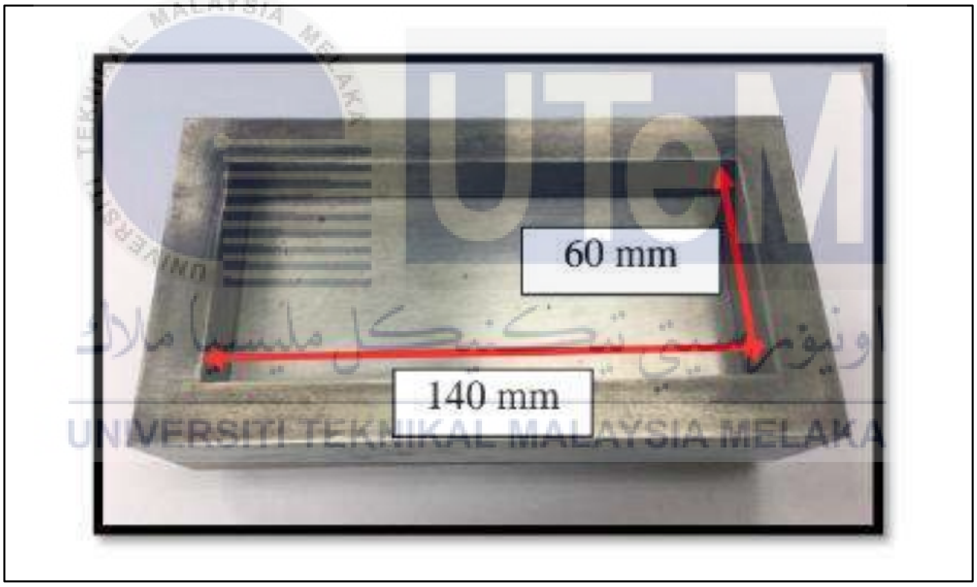


Figure 3.6 Mould Dimension

Figure 3.8 Hot Press Machine

Figure 3.7 De-mold machine


Figure 3.9 Cutting Machine


Figure 3.10 Digital scale

Figure 3.11 Blender

Figure 3.13 Oven

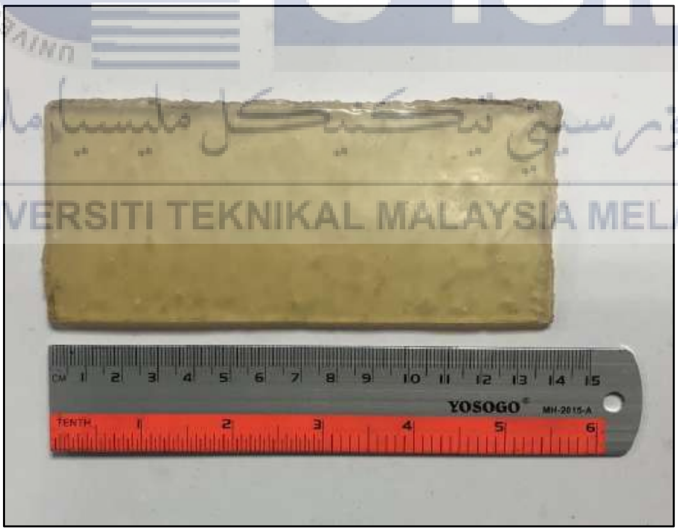


Figure 3.12 Sample dimension

Weigh the corn starch according to ratio by using digital scale.

Weigh the glycerol according to ratio by using digital scale.

Put weighed corn starch and glycerol together in the container.

Mixed corn starch and glycerol manually by hands.

Dry mixing the material by using blender for 2-3 minutes.

Put the blended material in the prepared mould.

Close the mould tightly and carefully.

Hot press the mould for 15 minutes then curing for 15 minutes by using Hot Press Machine.

After curing process, de-mould by using press machine to take out the sample.

The cutted sample is ready for testing.

Cut the sample according to testing standard by using cutting machine.

Cured of corn starch and glycerol mixture.

Figure 3.14 Fabrication of thermoplastic corn starch in flow chart form

3.5 Physical testing

3.5.1 Moisture content

According to the previous study Jumaidin et al., (2017), for moisture content, the sample (10 x 10 mm) were prepared for the moisture content investigation. All the samples were dried in an oven for 24 h at 105 °C. Weight of samples, before (M_i) and after (M_f) the heating was measured in order to calculate moisture content. The moisture content was determined by using Equation 3.1. The test were conducted in a few replications and the average value was computed.

$$\text{Moisture content (\%)} = \frac{M_i - M_f}{M_i} \text{x} 100 \qquad 3.1$$

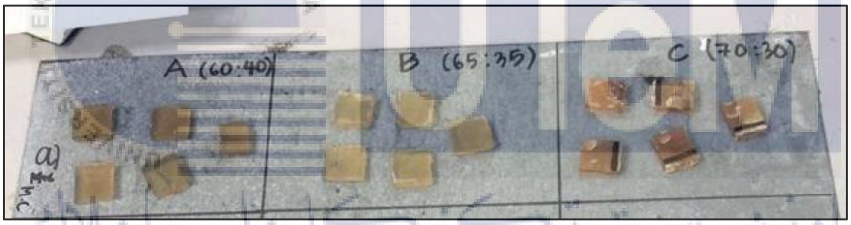


Figure 3.15 Samples for Moisture Content after dried in oven

3.5.2 Density

Based on the previous study, (Zuraida et al., 2012), the density testing of thermoplastic corn starch was carried out with the use of a high-precision electronic balance, densimeter, MD-300S model. By using Equation 3.2 below for density measurement.

$$\boldsymbol{\rho = \frac{m}{v}} \qquad 3.2$$

Figure 3.16 Electronic Densimeter

3.5.3 Water absorption

Based on the study of Jumaidin et al., (2017), specimens having dimensions of 10 x 10 mm x 3 mm were dried in an air circulating oven at 105 ºC ± 2 for 24 h to remove existing moisture, followed by immersing in water at room temperature (23 ± 1 ºC) for 0.5, 2 and 24 h, respectively, as mentioned in some previous studies (Lomelí Ramírez et al., 2011; Sahari et al., 2012). The samples were weighed before (W_i) and after immersion (W_f) and water absorption of the laminates was calculated using Equation 3.3. The test was conducted in a few replications and the average value was computed.

$$\textbf{Water absorption } (\%) = \frac{W_f - W_i}{W_i} \text{x } 100 \qquad \textbf{3.3}$$

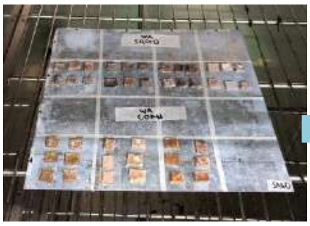
 Dried the sample in the oven at 105°C for 24 hours	 The initial weight is taken	 Immersed the samples in 20mm depth of water and leff for 30 minutes and 2 hours
 Then, the final weight is taken.	 Dried the sample in the oven at 105°C for 24 hours .	 Filtered the sample by using filter paper and ready for the next dried process

Figure 3.17 Water absorption testing

3.6 Environmental testing

3.6.1 Soil burial

For this testing, five samples (10 x 10 x 3 mm) for each ratio, were buried at 10 cm depth in soil which was regularly moistened with distilled water. The average environmental temperature and relative humidity (RH) for the testing is 26±4 °C and 76±4% RH, the ph of the soil is 6.5, and the moisture content is 28±8%. PVC net was used up to wrap the samples before burying into the soil to facilitate removal of the degraded samples while maintaining the access of moisture and microorganism.

Prior to testing, samples were dried at 105 °C for 24 h and weighed to obtain the initial weight, W_i. Two sets of experiments were carried out at two-week and four-week intervals. At predetermined intervals, soil samples were collected and gently cleaned with distilled water to remove impurities. Afterwards, they were dried at 105°C for 24 hr and weighed to obtain the final weight, W_f. The weight loss of samples was determined using Equation 3.4. The procedure was followed as the previous study (Ridhwan Jumaidin et al., 2020).

$$\text{Weight loss (\%)} = \frac{W_f - W_i}{W_i} \times 100 \qquad \textbf{3.4}$$

Took the initial weight of the samples before dried in the oven for 24 hours at the temperature of 105°C.

After dried in the oven, put the sample on top of 20mm soil

Then, buried the sample in soil in 10cm depth.

The soil watered regularly to maintain the moisture of the soil for two weeks.

After two weeks, take out the sample from the soil and then dried again in oven for 24 hours, 105°C temperature

After dried in oven, cleaned the samples and the final weight is taken.

Figure 3.18 Soil Burial testing

3.6.2 Water solubility

Water solubility (WS) of the samples is determined according to the previous method from Jumaidin et al., 2017), with a slight modification. For this, piece of sample (10 mm x 10mm x 3 mm) was cut and dried at 150 °C ± 2 for 24 hr. The initial weight of samples (W_o) was measured before immersing into 30 mL of distilled water with gentle stirring. After 8 h of immersion, the remaining piece of sample, taken from the beaker and filter paper, was used to remove the remaining water on the surface. Then, the sample was dried again at 150 °C ± 2 for 24 hr to determine the final weight (W_f). The water solubility of the sample was calculated by using Equation 3.5. The test was conducted in a few replications and the average value was computed (Jumaidin et al., 2017).

$$\textbf{Water solubility } (\%) = \frac{W_o - W_f}{W_o} \text{ x } 100 \qquad \textbf{3.5}$$

 After 24 hours dried in oven with 105°C temperature, take the initial weight of samples gently stirred before immersed for 24 hours in 20mm depth of water.	 After immersed for 24 hours in 20mm depth water, the sample dried again in oven for 24 hours with the same temperature, 105°C.	 Then, after dried 24 hours in oven, the final weight of the samples is taken.

Figure 3.19 Water Solubility samples testing

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will discuss the data and result that were drawn from the testing and observations that began on the first day of the experiment. Environmental tests, such as soil burial testing and water solubility testing, were used to evaluate the hypothesis on the influence of thermoplastic corn starch. Water absorption, density, and moisture content are the other three physical tests mentioned. Tables, graphs, and figures that indicate the outcome are displayed to demonstrate and make it more understandable.

4.2 Fabricated sample

Table 4.1 below shows the samples of corn starch mixed with glycerol with different ratios. The higher the content of starch, the less the sample is cooked. The condition of the sample that used 80 wt.% of starch is uncooked, also same goes to the sample that used 75 wt.% were partially overcooked or brittle and uncooked due to low content of glycerol. The samples from these two ratios cannot be used or are unsuitable to used for testing. As mentioned by (Zakaria et al., 2021), 20 wt.% and 25 wt.% of glycerol mixtures remained brittle and powdery. Meanwhile for 65 wt.% of corn starch, it is suitable to used for testing because (Zaaba & Ismail, 2020) stated that, the addition of glycerol as a plasticizer in more of 20% is enough to plastify the starch. Higher content of glycerol, on the other hand, soften the starch and cause it to become overplasticized.

Table 4.1 Samples of thermoplastic corn starch + glycerol with different ratio

Ratio	Figure of samples
60:40	
65:35	
70:30	
75:25	
80:20	

4.3 Physical testing

4.3.1 Density

The density of a material is an essential attribute to consider throughout the material selection process. This is because density may have an impact on the finished product's performance in a variety of ways, including weight, manufacturing and handling procedures, ease of use, transportation costs, and energy usage. It's critical to look at the effects of the density of thermoplastic in order to see whether this biopolymer has the potential to replace non-biodegradable polymers (Jumaidin et al., 2017). For density testing, (Zuraida et al., 2012) had mentioned that the particle spacing is also represnted by the glycerol/starch ratio. Lowering the ratio resulted in tighter spacing between the starch particles, resulting in fewer voids and a denser material.

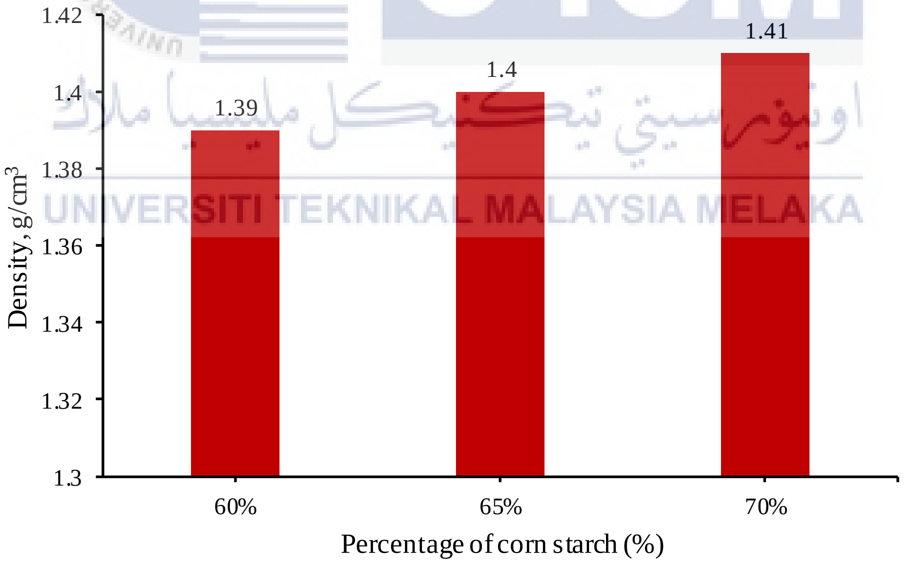


Figure 4.1 Density of Thermoplastic Corn Starch

The density of thermoplastic corn starch is shown in Figure 4.1. The densities of thermoplastic corn starch are 1.39 g/cm^3, 1.40g/cm^3, and 1.41g/cm^3 for 60, 65, and 70 wt%

of corn starch compositions, respectively, according to Figure 4.1. The maximum density occurs at 70 wt% thermoplastics corn starch (1.41 g/cm^3), while the lowest density occurs at 60 wt% thermoplastics corn starch (1.39 g/cm^3). The difference in density decrease between the higher and lower density findings is roughly 0.02%. This demonstrated that when glycerol levels dropped, the density of thermoplastic corn starch increased linearly.

4.3.2 Water Absorption

Considering starch and agar are both polysachharides that are known to be moisture sensitive, it is crucial to investigate the water absorption capacity of the two materials in combination. Agar is made composed of agarose and agaropection, both of which are hydrophilic due to the creation of a bond between the hydroxyl group and the oxygen bond with water in starch. This is one of the primary reasons for thermoplastic starch and agar’s hydrophilic behaviour (Jumaidin et al., 2017). The water absorption behaviour of thermoplastic corn starch has a significant impact on its dimensional stability (shelf life) and mechanical properties (Bergel et al., 2018). Water is known to be particularly sensitive to biopolymer compounds. As a result, it's crucial to look at the water absorption capabilities of the completely bio-based material developed in this research. A water absorption test is widely performed to determine how much water a material absorbs over a period of time (Jumaidin, Saidi, et al., 2019).

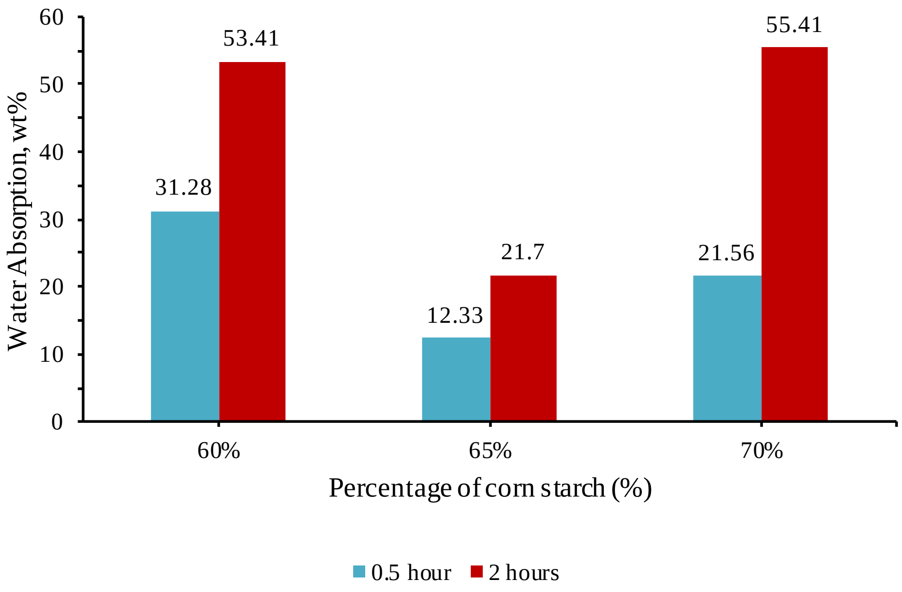


Figure 4.2 Water absorption of Thermoplastic corn starch

The findings of water absorption in two separate period of times which are 0.5-hour and 2 hours, are shown in the Figure 4.2. Only 12.33 wt% of corn starch was evaluated at 0.5 hours for a 65% content of corn starch composition. Meanwhile, with 60% corn starch content, the greatest rate of water absorption is 31.28 wt%. As for period of 2 hours, the result shows that 65% content of corn starch has the lowest water absorption compared to 60% and 70% corn starch content. The result is related to (Jumaidin, Saidi, et al., 2019), stated that the non-homogenous structure of the composites, which led to inconsistent water absorption behaviour, might be to responsible for the composites' fluctuating water absorption behaviour. As predicted, a 0.5-hour interval resulted in a lower rate of water absorption than a 2-hour period. Furthermore, the hydrophilic behaviour of thermoplastic might explain the increased water absorption as mentioned in previous study by (Zakaria et al., 2020).

4.3.3 Moisture Content

The equilibrium moisture content of thermoplastic was measured using moisture content. The moisture content of the material is an essential factor that may affect the end-dimensional product's stability. A prior research found that moisture content has a significant impact on material water absorption behaviour, with increased moisture content resulting in greater water absorption capacity (Jumaidin et al., 2017). Before evaluating a new possible natural material for polymer bio-composites, moisture content is a crucial aspect to examine. The stability of the bio-composite in terms of strength, dimensions, and porosity formation may be affected by high moisture content. As a result, the composite's low moisture content value is suitable for future exploration (Zakaria et al., 2020).

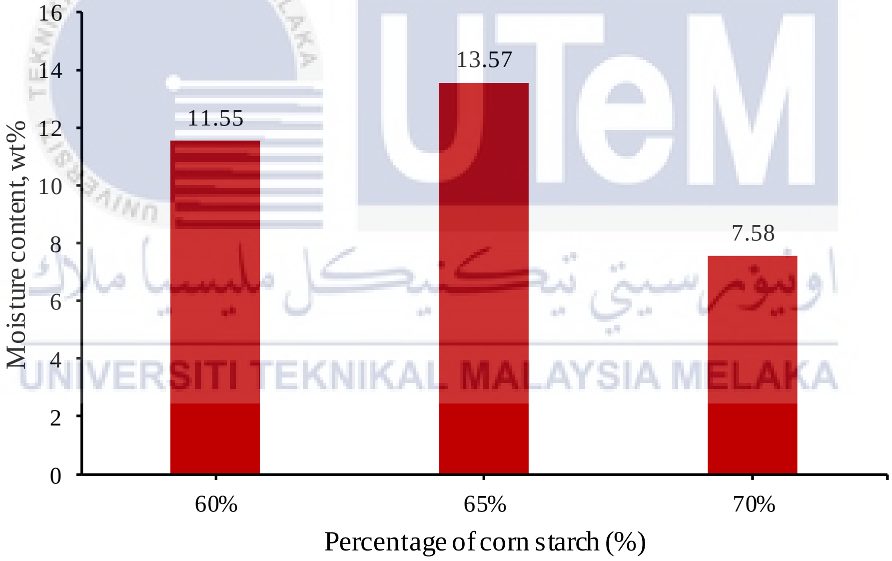


Figure 4.3 Moisture Content of Thermoplastic corn starch

The moisture content of a substance is defined as the amount of water that might be removed from it without affecting its chemical composition when compared to the material’s base weight. As shown in Figure 4.3, corn starch with content of 65% and 60% had 13.57 wt% and 11.55 wt% whereas 70% of corn starch showed the lowest moisture content. This circumstances is related to study by (Zakaria et al., 2021) which stated that with additional plasticizer(glycerol), the combination of corn starch and glycerol becomes more hydrophilic. As a result, tests have shown that as greater plasticizers are added, the moisture content rises. Also, as mentioned by (Zuraida et al., 2012) about moisture content, this occur due to hydrophilic nature of starch and is proportional to the volume of spaces between starch particles.

4.4 Environmental Testing

4.4.1 Water Solubility

The term “water solubility” refers to a material’s ability to resist water. Water solubility, in other hand, indicates how a substance degrades when immersed in water (Jumaidin et al., 2017). Also, there are certain drawbacks to thermoplastic starch, such as its higher water solubility. As a result, water solubility tests for matrix and composite materials should be analyzed and evaluated by determining the weight loss of the material after continuous stirring for a certain period of time (Jumaidin, Adam, et al., 2019). The solubilitiy of a bio-composite is an important paramenter since it reflects the product’s integrity in an aqueous environment and also supports in the decision of the product’s application (Diyana, Jumaidin, Selamat, & Suan, 2021)

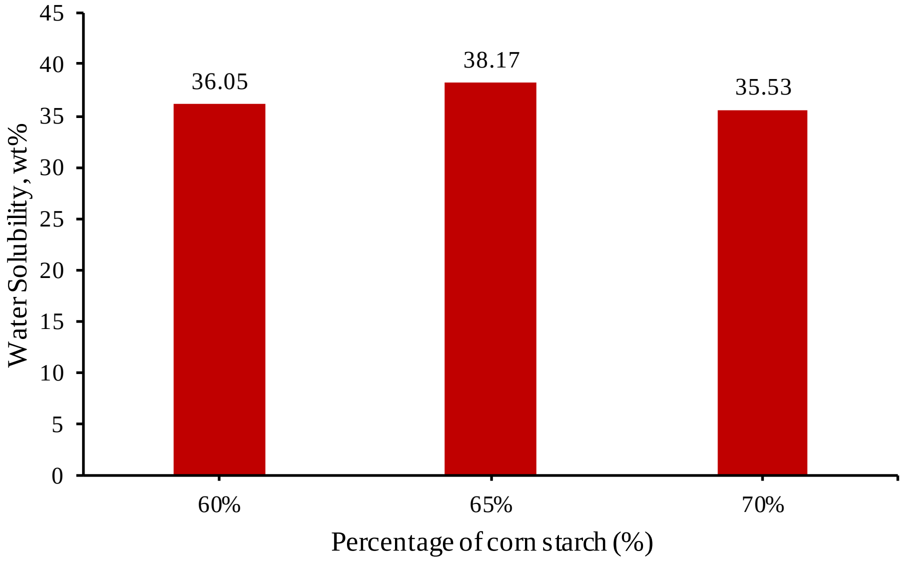


Figure 4.4 Water solubility of thermoplastic corn starch

Figure 4.4 shows the water solubility of thermoplastic corn starch, which reveals the materials' water resistance when immersed in water and continuously stirred. After immersed in water for 24 hours, the 60% of corn starch shows 36.05 wt% of water solubility. Meanwhile 38.17 wt% for 65% of corn starch which the highest too. Lastly for 70% of corn starch shows the lowest water solubility, 35.53 wt%. This circumstances can be compared to study by (Jumaidin, Saidi, et al., 2019) which stated that the lesser solubility of the composites compared to pure thermoplastic corn starch might be ascribed to the better water resistance of cogon grass fiber, which helps to prevent water absorption, which could lead to material breakdown and dissolving. This statement also supported by (Jumaidin, Adam, et al., 2019), specified that the abundance of free hydroxyl groups on the repeating unit of starch molecules in the thermoplastic potato starch matrix allows it to absorb more water, resulting in its hygroscopic nature. This data also indicates that the thermoplastic potato starch/sugarcane fiber composite is marginally more water resistant than the thermoplastic potato starch matrix. This might be influenced by the fact that fiber is less hygroscopic and more crystalline than starch.

4.4.2 Soil Burial

The weight loss due to moisture and microorganism activity during the soil burial phase can be used to estimate a material's biodegradation characteristic (Jumaidin et al., 2020). During the soil burial phase, the weight loss of the material can be used as a primary indicator of the biodegradation process by moisture and bacteria (Zakaria et al., 2020). Composites were tested in the soil to see if they degraded (Sapuan et al., 2013).

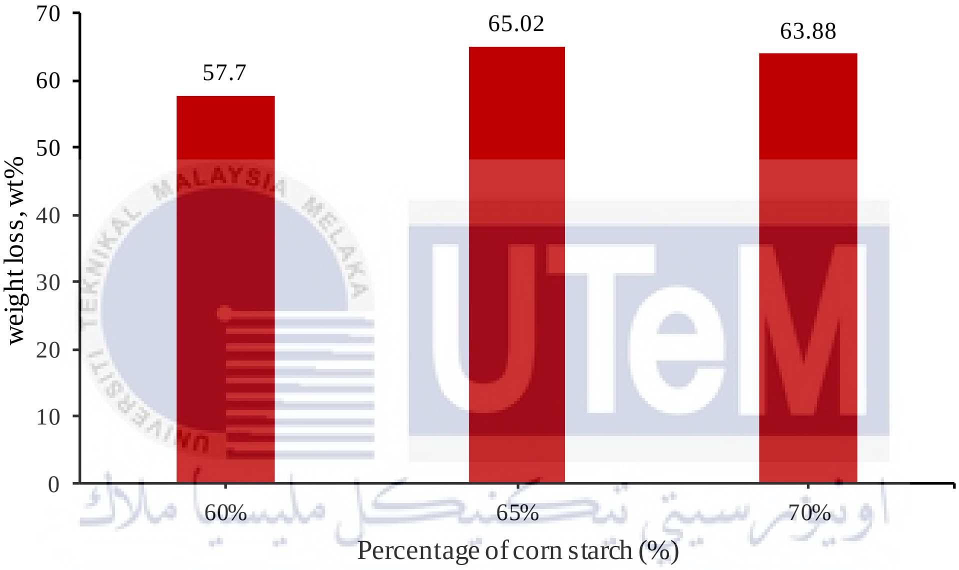


Figure 4.5 Soil Burial of thermoplastic corn starch

Figure 4.5 above shows the weight loss of thermoplastic corn starch after 2 weeks of soil burial testing. The weight loss of soil burial for 60% of corn starch is 57.70 wt%. Then 65.02 wt% for 65% of corn starch content, lastly 63.88 wt% for 70% of corn starch. It is obvious that the graph shows that 60% is the lowest and 65% is the highest weight loss. To be associated with this situation, (Azahari et al., 2011) mentioned that, since corn starch is more biodegradable than pure PVOH, this observation was attributed to the film's corn starch concentration. Along with its high hydrolysability, the PVOH is biodegradable and has a stronger resistance to soil burial degradation. Compost is made up of organic elements that have degraded mostly via aerobic decomposition. It might be a nutrient-dense food. Compost may operate as a soil conditionner, fertilizer, source of important humus or humic acids, and natural pesticide for soil, among other things. The nutrients in compost might speed up the desomposition of the film compared to unimproved soil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The result of this project shows that thermoplastic corn starch it was successfully produced via blender and hot press after several time s of failed. A good compatibility between corn starch and glycerol which led to improvement in the properties of the material was revealed. From five ratios mixture of corn starch and glycerol, only three ratios are suitable to be tested. This is because the condition of last two thermoplastic ratios which are 75% and 80% content of corn starch is uncooked and brittle after the hot press process. In conclusion, thermoplastic corn starch already proved that it can be potential as alternative material for non-environmentally friendly plastic which biodegradable.

5.2 Recommendation

There are some recommendations provided to extend understanding of corn starch behaviour from this project, which are as follow:

- Suggest various type of plasticizers such as sorbitol, urea, fructose and other to investigate the behaviour and properties of corn starch.
- To increase the strength of thermoplastic. by adding multiple forms of plant fibers such as kenaf, banana leaf, pineapple leaf, bamboo, and others.

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APPENDICES

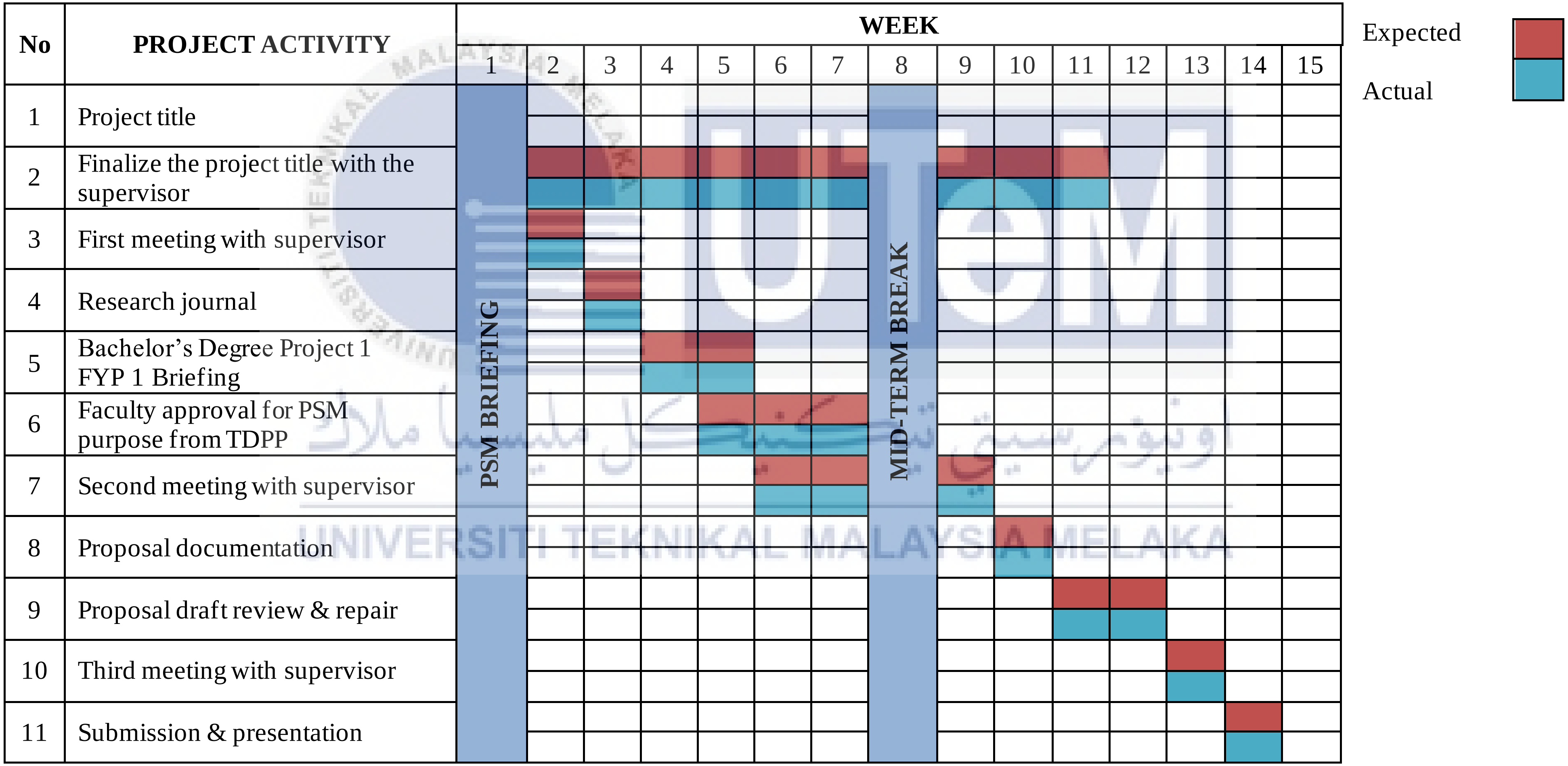
APPENDEX A
GANTT CHART PSM 1

No	PROJECT ACTIVITY	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project title	PSM BRIEFING							MID-TERM BREAK							
2	Finalize the project title with the supervisor		🟥													
			🟦													
3	First meeting with supervisor		🟥													
			🟦													
4	Research journal			🟥												
				🟦												
5	Bachelor's Degree Project 1 FYP 1 Briefing				🟥											
					🟦											
6	Faculty approval for PSM purpose from TDPP					🟥										
						🟦										
7	Second meeting with supervisor						🟥									
							🟦									
8	Proposal documentation			🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥	🟥			
				🟦	🟦	🟦	🟦	🟦		🟦	🟦	🟦	🟦			
9	Proposal draft review & repair						🟥	🟥		🟥	🟥	🟥	🟥			
							🟦	🟦		🟦	🟦	🟦	🟦			
10	Third meeting with supervisor													🟥		
														🟦		
11	Submission & presentation														🟥	
															🟦	

Expected 🟥
Actual 🟦

APPENDICES

APPENDIX B
GANTT CHART PSM 2



No	PROJECT ACTIVITY	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project title	PSM BRIEFING							MID-TERM BREAK							
2	Finalize the project title with the supervisor		🟥	🟥	🟥	🟥	🟥	🟥		🟥	🟥	🟥				
			🟦	🟦	🟦	🟦	🟦	🟦		🟦	🟦	🟦				
3	First meeting with supervisor		🟥													
			🟦													
4	Research journal			🟥												
				🟦												
5	Bachelor's Degree Project 1 FYP 1 Briefing				🟥	🟥										
					🟦	🟦										
6	Faculty approval for PSM purpose from TDPP					🟥	🟥	🟥								
						🟦	🟦	🟦								
7	Second meeting with supervisor						🟥	🟥		🟥						
							🟦	🟦		🟦						
8	Proposal documentation										🟥					
											🟦					
9	Proposal draft review & repair											🟥	🟥			
												🟦	🟦			
10	Third meeting with supervisor													🟥		
														🟦		
11	Submission & presentation														🟥	
															🟦	

Expected	🟥
Actual	🟦

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: **INVESTIGATION OF PHYSICAL AND ENVIRONMENTAL BEHAVIOUR ON CORN STARCH**

SESI PENGAJIAN: **2020/21 Semester 1**

Saya **NUR'AIN NAZZEHA BINTI ANUAR**

mengaku membenarkan tesis ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☑	TIDAK TERHAD	

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NO. 3D LORONG BOUGENVILLA 7A
TAMAN SITI NURBAYA BATU 8, JALAN ULU OYA
98000 SIBU, SARAWAK

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Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya,
76100 Durian Tunggal,
Melaka, Malaysia.

+606 270 1000
+606 270 1022
www.utem.edu.my

FAKULTI TEKNOLOGI KEJURUTERAAN MEKANIKAL DAN PEMBUATAN
Tel : +606 270 1184 | Faks : +606 270 1064

Rujukan Kami (Our Ref):
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Chief Information Officer
Perpustakaan Laman Hikmah
Universiti Teknikal Malaysia Melaka

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Nama pelajar: NUR'AIN NAZZEHA BINTI ANUAR (B091810048)
Tajuk Tesis: INVESTIGATION OF PHYSICAL AND ENVIRONMENTAL BEHAVIOUR ON CORN STARCH

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"
"KOMPETENSI TERAS KEGEMILANGAN"

Saya yang menjalankan amanah,

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Penyelia Utama/ Pensyarah Kanan
Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan
Universiti Teknikal Malaysia Melaka

NAZZEHA

by Nur Faresha

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CHAPTER 1

INTRODUCTION

1.1 Background

Composites are made up of two materials, one of which is called the reinforcing phase and comes in the form of fibers, papers, or particles, and the other is called the matrix phase and it is embedded in the reinforcing phase. Environmental issues have resulted in considerable interest in the development of new composite materials based in biodegradable resources. The thrust on developing innovative and weight less material from locally available, cheaper and renewable sources was of greater interest (Sathishkumar et al., 2013).

Nowadays, our world is facing problems with one of the biggest pollution which is plastic pollution. Plastic waste is a major contributor to environmental pollution because it needs thousand years to disposed. This issue is important becasue it can cause a serious damage to environment through it non-stop production and destruction. Plastic contains toxic chemical which can lead to harm effect towards air, water, earth, animals and humans (Azahari et al., 2011).

As a result, much focus has been given on the development of various biodegradable materials in order to address this serious issue (Azahari et al., 2011). Being biodegradable means that it can be degraded by the enzymatic actions of microorganisms such as bacteria, fungi, algae, and so on. So, in general, biodegradable materials are derived from natural renewable sources and starch, cellulose, lignii, chitin, protein., are the most common examples of natural biodegradable polymers (Ruhul Amin et al., 2020).

Starch is one of the most promising materials due to its availibility, economic, abundant, biodegradable, and renewable (Jumaidin et al., 2016). Starch can be the option as it is the least expensive biopolymer among the natural polymers, and starch is found in abundance in corn, potato, rice, and many other natural sources (Ruhul Amin et al., 2020). Besides starch, glycerol is one of the material that needed in producing of thermoplastic. Glycerol is a chemical that has a multitude of uses in the pharmaceutical, cosmetic, and food industries and it is also an organic compound. Glycerol is derived from natural or petrochemical feedstocks (Tan et al., 2013). However, starch-based biodegradable products reveal some disadvantages attributed mainly to starch's highly hydrophilic character (Ribba et al., 2017).

1.2 Problem Statement

These days, petroleum-based polymers have caused harm to the environment due to their production from a non-biodegradable material. This situation has to lead the world to plastic pollution. Moreover, non-biodegradable plastic also threatens food safety and quality, coastal tourism, ocean health, human health and contributes to climate change. And most visible and distressing impacts of petroleum-based plastics in marine life are suffocation, ingestion, and entanglement of hundreds of marine species (Ridhwan Jumaidin et al., 2020). Hence, a possible way to solve these issues is to produce a thermoplastic using biodegradable material. Thus, the purpose of this study is to produce biodegradable plastics that are eco-friendly and safe for the environment to replace petroleum-based plastics by using corn starch and glycerol.

1.3 Research Objective

The objectives of this study are as follows:

a) To produce the matrix by using biodegradable material which is corn starch.

b) To investigate the physical and environmental behaviour of corn starch in various plasticizer loadings.

1.4 Scope of Research

The scope of this research are as follows:

- To prepare and fabricate a matrix sample test from corn starch mix with plasticzer (glycerol).
- To characterize the matrix on biodegradability using soil burial testing and water solubility method.
- To find the physical behaviour by using density, moisture content and water absorption testing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of composite materials dates back centuries and began with natural fibers. Clay was reinforced with straw to build walls and buildings in ancient Egypt around 3000 years ago. Metals, for example, were later introduced as more durable building materials (Raj et al., 2021). Composites are materials that are created by mixing two or more natural or artificial elements with various physical or chemical qualities to create a substance that is stronger as a group that as separate components. To optimise the result of the end of the product, the component materials (matrix and reinforcement) do not mix entirely or lose their valuable qualities (Raj et al., 2021).

Composite materials, in particular, are being invented and redesigned with the goal of improving and adapting traditional products while also introducing new products in a sustainable and appropriate way. Natural fibers are mostly derived from plants or animals. The first is primarily made of cellulose, whereas the latter is made of protein. Natural fibers are commonly referred to as vegetable fibers in the composited industry. One of the problems with natural fibers is the lack of information and mechanical variances. Furthermore, the lack of industry standards for both producers and users of these materials in term of how to collect, treat, process and post-process natural fibers adds to the selection process' complexity. These concerns are, in fact, major deterrents to the general use of natural fibers in a variety of applications. To fill this void, this study presents a study of various mechanical properties of natural fibers and their applications (Peças et al., 2018).

In addition to being environmentally friendly, composites made of biodegradable polymetric matrixes reinforced with natural fibers have remarkable mechanical properties (Beltrami et al., 2014). Biodegradability refers to the ability of microorganisms such as bacteria, fungi, algae, and others to decompose by enzymatic activity. In general, biodegradable materials are generated from natural renewable sources, such as starch, cellulose, lignin, chitin, protein, and other natural biodegradable polymers being the most common examples (Ruhul Amin et al., 2020). Figure 2.1 shows the flowchart of Biocomposite.

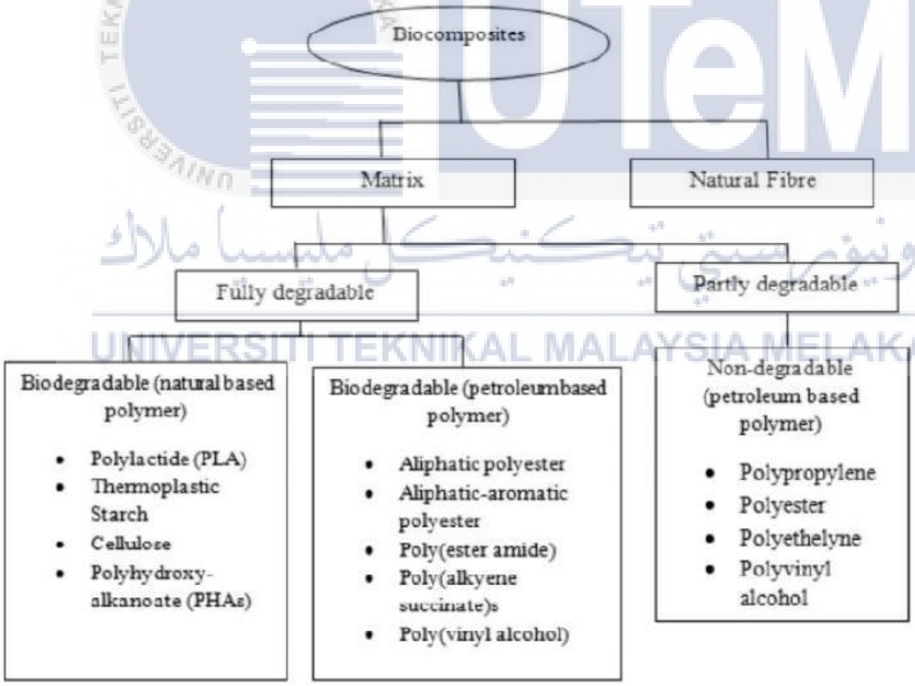


Figure 2.1 Classification of biocomposite (Sahari & Sapuan, 2012)**.**

2.2 Matrix

2.2.1 Introduction of matrix

A composite has a continuous component known as the matrix and a discrete or discontinuous component known as the fillers. The matrix and the fillers combine to form one material in the composite material. The filler is the load bearing component of the composites, while the matrix, which is the reinforcing material, holds the filler together (Ruano et al., 2016). Even though the reinforcement improves the overall characteristics of the matrix, the matrix holds the reinforcement in order to create the desire shape (Sharma et al., 2020).

2.2.2 Type of matrix

There are various types of composites. Ceramic matrix composites (CMC), polymer matrix composites (PMC), and metal matrix composites (MMC) are the type of composite (Ruano et al., 2016). The type of matrix is shown in Figure 2.2.

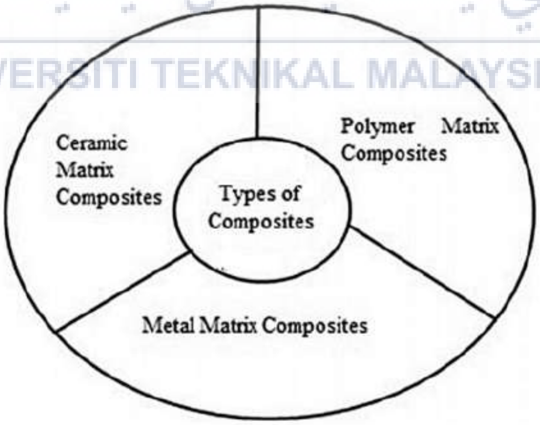


Figure 2.2 Type of matrix (Sharma et al., 2020)

Ceramic Matrix Composites (CMCs) are a mixture of ceramic particulates, fibers, and whiskers with a matrix of another ceramic and can be defined as solid materials with highly strong bonding that is typically ionic but can be covalent in a few cases. Ceramics, metals, glasses, and polymers can be used to reinforce the ceramic matrix. Ceramic-based matrix materials exhibit exceptional corrosion resistance, high melting points, superior compressive strength, and temperature stability. Ceramic matrices are a popular material for high-temperature applications such as pistons, blades, and rotors in gas turbine parts. They can withstand high temperatures and perform well in corrosive environments. The primary goals in the development of CMCs are to improve toughness because monolithic ceramics are brittle while having high stiffness and strength. It is undeniable that reinforcement, in the form of particulates and continuous fibres, has resulted in an increase in toughness, but the increase is even greater for the second, oxide-based or non-oxide-based CMCs, as illustrated by a comparison of modulus of elasticity of a few ceramics in Figure 2.3 below (Sharma et al., 2020).

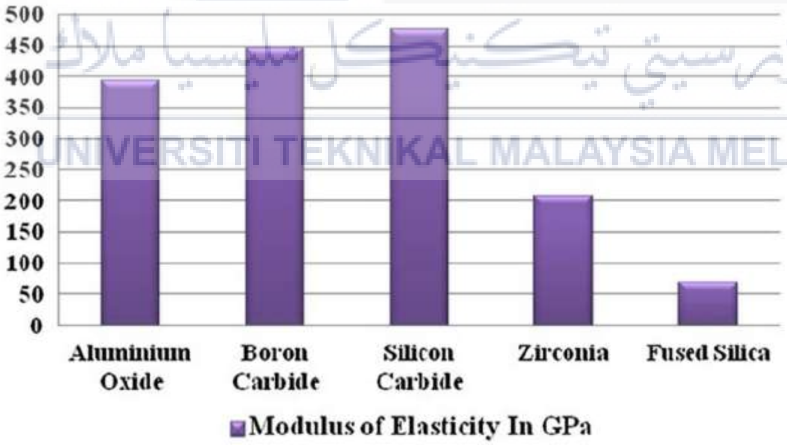


Figure 2.3 Modulus of Elasticity of ceramic materials (Sharma et al., 2020).

The main disadvantage of CMCs is that they fail at low strain, which limits the stress in the fiber at lower levels. It has a relatively high modulus and lower ductility, which protects against variable thermal stresses caused by variations in thermal expansion.

Next is polymer matrix composites (PMCs). Currently, PMCs are the most commonly used composites among the available composites. The matrix in PMCs is typically reinforced with ceramic fibers due to their high strength in comparison to the matrix material. The matrix, reinforcement, process parameters, microstructure, composition, and interphase all influence the properties of PMCs. PMCs are well-known for their low cost and simple manufacturing process. PMC manufacturers can create cost-effective products using a variety of manufacturing procedures. Each manufacturing process has characteristics that define the type of product that will be produced. This knowledge enables the manufacturer to provide the best option for the consumer. Polymer matrix composites are made up of a thermoplastic or thermosetting plastic matrix and one or more reinforcement materials such as carbon, glass, steel, and natural fibres. Polymers make good components because they are easily processed. Polymers are notable for their light weight. Polymer composite composites (PMCs) have numerous properties. Some of them are high strength, excellent impact, compression, and fatigue properties; cost-effective manufacturing and tooling processes, outstanding chemical and corrosion resistance, chemical inertness at a low cost, and good mechanical characteristics. PMCs are commonly used in rockets, aircraft, and sporting equipment (Sharma et al., 2020).

This matrix performs five important functions. The first function is to keep the reinforcement phase in place. Second, under applied loads or stress, deforming and distributing stress to the reinforcement. The fibers are then bound together, transferring load to them, and providing rigidity and shape to the structure. Following that, the fibers are isolated so that individual fibers can act independently, and crack propagation is stopped or slowed. Finally, the reinforced fibers are protected from chemical attack and mechanical damage (My et al., 2017).

Metal Matrix Composites (MMCs) are widely regarded as cutting-edge materials. MMCs outperform conventional materials in terms of improved mechanical and thermal properties, including high wear resistance and exceptional thermal conductivity. The mechanical properties of some metals that are commonly used as a matrix are depicted in the Figure 2.4, Figure 2.5, Figure 2.6 below. At the moment, the most common matrix metals are aluminium, copper, iron, magnesium, nickel, and titanium (Sharma et al., 2020).

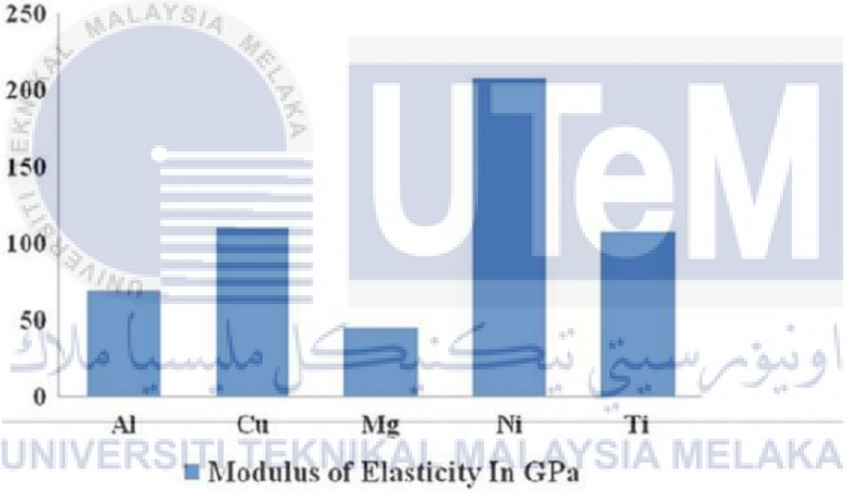


Figure 2.4 Modulus of elasicity for different metals normally used as matrix material (Sharma et al., 2020).

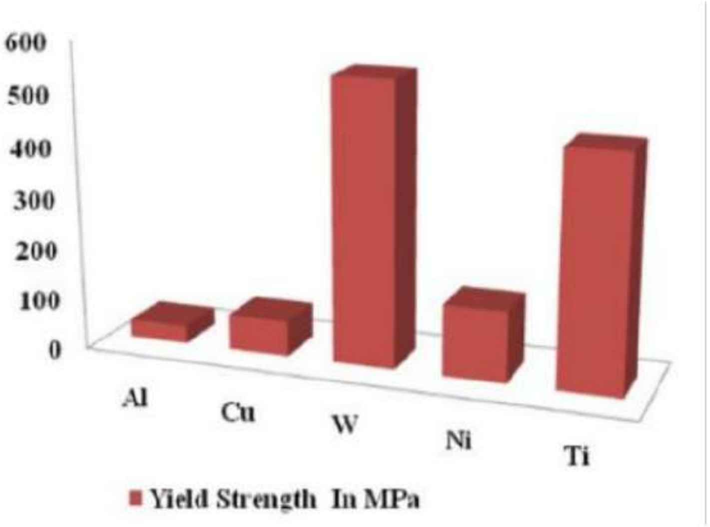


Figure 2.5 Yield Strength in Mpa (Sharma et al., 2020).

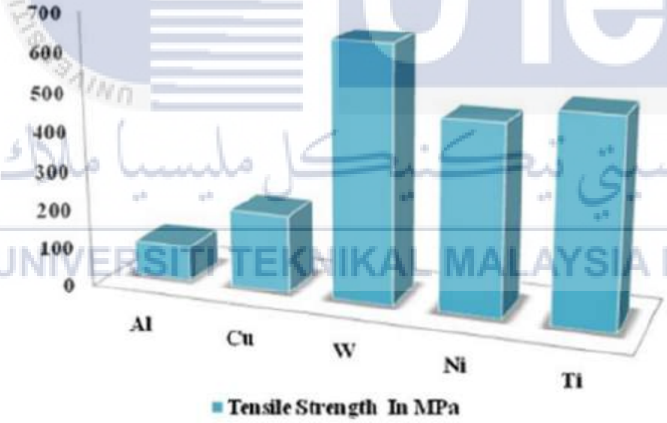


Figure 2.6 Comparison of Tensile Strength of metals commonly used as matrix material (Sharma et al., 2020)

Aluminium alloys are commonly used in structural applications in the automotive and aerospace industries due to their good forming and joining properties, low density, excellent strength, and corrosion resistance. Ceramic particles are mixed into a composite material to increase the strength of aluminium and its alloys. Titanium-based composites have numerous applications, particularly as a material for high-temperature structures. Titanium alloys are commonly used in aerospace components due to their superior high-temperature strength and corrosive resistance. The material, on the other hand, is pricey. Magnesium is the lightest of a group of nonferrous metals, and it is commonly used in electronics, chain saw housings, and gearbox housings for aerospace applications. Copper is a metal that can be easily cast and formed. Copper-based composite materials with excellent wear resistance are used in electronics as electrical contacts and system elements. Metal matrix composites have sparked a lot of interest recently for potential industrial applications. MMCs have a wide range of potential applications in a variety of industries. Recent research in the field of MMCs revealed the potential for producing composites with exceptional mechanical properties. These MMCs have the potential to be a perfect substitute for expensive conventional alloys used in structural and functional applications. For advanced structural applications, aluminium matrix composite is recommended (Sharma et al., 2020).

In order to obtain more commercially viable products, more effective fabrication methods are required; therefore, a variety of procedures are used in the manufacture of MMCs. The primary goal is to introduce additional effective, economical, and production techniques to meet the needs of various industries. A significant amount of research is being conducted in the field of MMC manufacturing, which has reduced its expenditure to a reasonable level. It is possible to achieve the desired properties for a specific application by using an appropriate combination of metal matrix and reinforcement. MMCs have metallic reinforcement properties. SiC, AI203, TinC, B4C, and TiB2 are common reinforcement particulates used to increase strength and modulus of elasticity. Among these, the incorporation of SiC and AI203 into the aluminium matrix results in improved properties (Sharma et al., 2020).

2.2.3 Biodegradable matrix

Many non-biodegradable petroleum-based polymers, such as polypropylene, polyethylene, and polystyrene, have raised several environmental problems, including waste generation, accumulation in disposal systems, and reproducibility, resulting in an increase in the volume of commercial and industrial dumps. As a result, researchers are interested in modifying existing materials to make them more environmentally friendly, as well as designing novel polymer composites from naturally occurring materials. There are numerous natural and synthetic polymers that degrade via hydrolytic (polycaprolactone, polyglycolide, plydioxanone, polylactides, polyhydroxyalkanoates) and enzymatic (polysaccharides, protein, polyaminoacids) mechanisms. Biodegradable polymers are derived from renewable resources that have been synthesised from chemicals. When exposed to environmental conditions, they are capable of decomposing. Biodegradable polymers have gotten a lot of attention because they are fully biodegradable into simple organic substances like hydrogen, carbon, and oxygen through interactions with microorganisms like algae, bacteria, and fungi (Chiellini et al., 2013).

Biodegradable polymers are classified based on their chemical composition, processing method, origin and synthesis method, application, economic importance, and so on. Because biodegradable polymers are found in nature during organism growth cycles, they are referred to as natural biodegradable polymers (Jha et al., 2019). The Figure 2.7 shows the flowchart of biodegradable polymer.

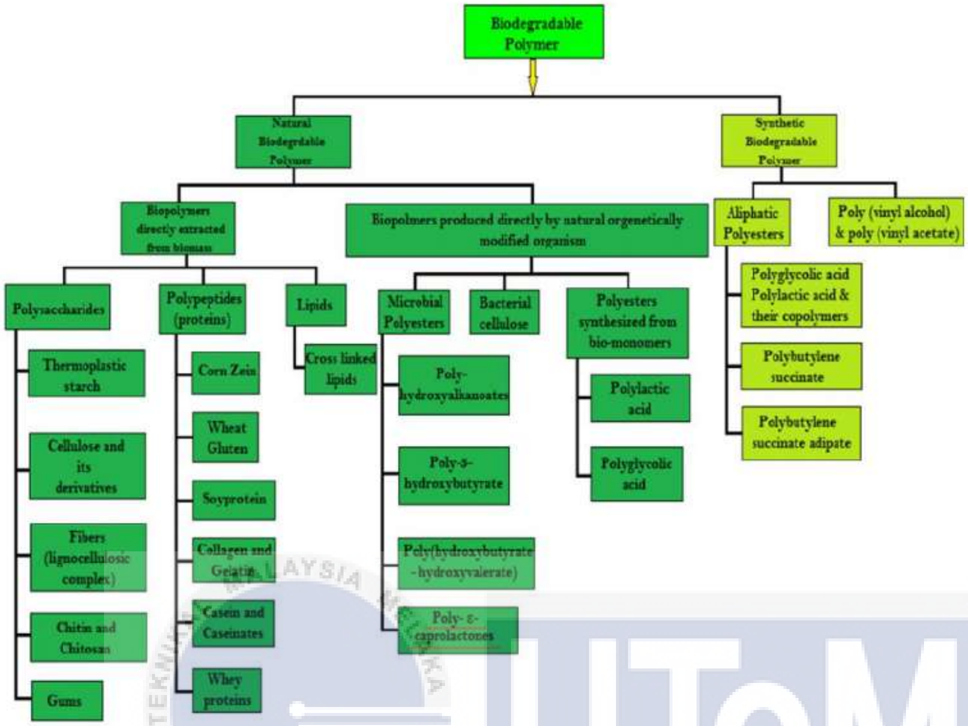


Figure 2.7 Classification of biodegradable polymers (Jha et al., 2019)

Polysaccharides are polymeric carbohydrate molecules that are made up of long chains of monosaccharide units that are joined together by glycosidic bonds. Natural occurring polysaccharides have distinct structural features in terms of molecular weight, monosaccharide composition, glycosidic linkage patterns, polysaccharide charging properties, such as solubility and rheological properties, which benefit their extensive applications in both food and non-food areas. Because most polysaccharides perform their functions in aqueous solution, understanding polysaccharide solubility is critical. This chapter specifically addressed the molecular mechanisms of polysaccharide solubility. It was discovered that there are relationships between polysaccharide solubility and molecular structures. It should also be noted that the current chapter only addressed polysaccharides in aqueous solution; the solubility of polysaccharides in other organic solvents was not addressed (Guo et al., 2017).

Thermoplastics are polymeric materials that can be reformed (melted and hardened) repeatedly while retaining their properties. This makes the material recyclable, which, in addition to being renewable and biodegradable, adds to its positive attributes (Jumaidin et al., 2019). Thermoplastic starch is created by disrupting the starch granule structure through the use of low water content starch and thermal and mechanical forces in the presence of a plasticizer (Ruhul Amin et al., 2020). Table 2.1 below shows the typical characteristics and applications of some thermoplastics.

Table 2.1 Typical characteristics and applications of some thermoplastics (Yashas Gowda et al., 2018).

Thermoplastics	Characteristics	Applications
Acrylics	Exceptional long-term exposure to sunlight and good light transmission.	Swimming pools, skylights, sinks and wash basins and on tail lights on automobiles.
Acrylonitrile-Butadiene-Styrene (ABS)	Outstanding impact strength and high mechanical strength.	Automotive parts, electrical and electronic applications, and packaging.
Polycarbonate	Excellent electrical insulating characteristics, strong, and rigid.	Packaging films, house wares, toys, containers, pipes, gasoline tanks, and coatings.
Polypropylene	Light-weight material and good insulation properties.	Packaging and foodservice products, automotive parts, radio and TV housing.
Polyamide-Imide	Exceptional mechanical, thermal and chemical resistance properties	Aerospace, heavy equipment and automotive

2.2.4 Advantages and disadvantages

The matrices have their own benefits and limitations. These are some of advantages that I have found in some journals. For polymer matrix, epoxy resin is usually recognized for advanced composites because of its properties such as good stiffness, corrosion, dimensional stability, and chemical resistance also good in thermal properties (Muhammad & Ahmad, 2013). Next, one of the benefits for ceramic matrix is that the heat shield system of space vehicles is exposed to temperatures above 1500°C for a few minutes during the re-entry phase. Only ceramic materials can withstand such conditions without significant damage, and only CMCs can hold up thermal shocks adequately. The development of CMC-based heat shield systems promises the following benefits: reduced weight, increased system load carrying capacity, reusability for multiple re-entries, and better steering during the re-entry phase with CMC flap systems (Basutkar & Kolekar, 2020).

For the polymer matrix, this kind of matrix serves as the binding material in the preparation of polymer composites (binder). It aids in the retention of fillers as well as the transmission of stress within the material. As a result, if the interfacial interaction is poor, the transmission of an externally applied stress will be poor, resulting in material failures (Ruano et al., 2016). Next, the limitations of metal matrix are the techniques of its fabrication can only be used with discontinuous reinforcements, also the costs are high, and the products are limited to the simple shapes that obtained by extrusion, rolling or forging. This is caused by complicated manufacturing processes of metal matrix (Haghshenas, 2016).

2.2.5 Examples of matrix

The example matrix for polymer matrix composites (PMCs) is epoxy, polyester and phenolic. Meanwhile for metal matrix composites (MMCs) is aluminium, titanium, and magnesium. Lastly, SiC, carbon, ZrB_2, HfB_2, Al_2O_3 is the example of matrix for ceramic matrix composites (CMCs). The examples of matrix are shown in Figure 2.8 below.

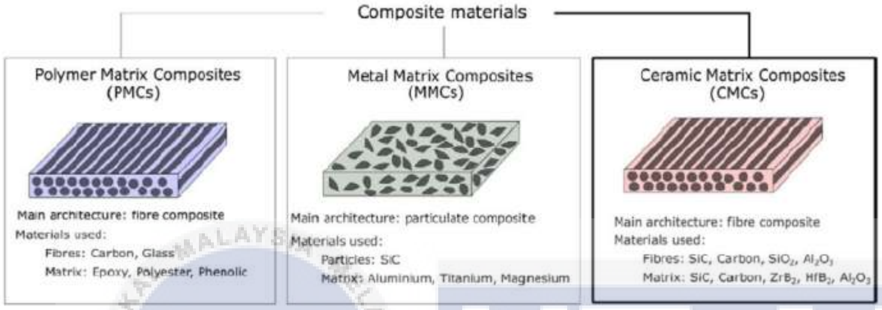


Figure 2.8 Classification of the composite materials depending on the nature of the matrix showing for each of them the main reinforcing architectures and materials used (Gavalda Diaz et al., 2019).

2.3 Starch

2.3.1 Introduction of starch

As a common polysaccharide, starch is a polymer made up of high number of saccharide molecules with the potential to be used as a biodegradable plastic (Abdullah et al., 2018). The two primary components of starch, amylose and amylopectin, have a significant impact on the physicochemical and functional qualities (Mir et al., 2017). Amylopectin is a highly branching structure of short -1,4 chains joined by -1,6 bonds, whereas amylose is a linear structure of -1,4 linked glucose units (Jumaidin et al., 2017).

Regardless of plant origins, amylose is a starch made up of two different forms of any anhydroglucose polymers. The macromolecules amylose and amylopectin, which represent for 98-99 percent of the dry weight, are referred to as amylose and amylopectin. When dissolved, amylose has a tendency to form insoluble semicrystalline aggregates due to its low degree of branching. In the production of such insoluble semicrystalline aggregates, the position of the branches in the amylose structure is also important. The next main component of starches is amylopectin, which is made up of a huge number of shorter chains with a lot of branches. Unlike linear amylose, which is primarily amorphous or semicrystalline, amylopectin has crystalline regions that render it insoluble even in hot water. Basically, the length of the amylopectin chain is thought to be the most important element in crystalline polymorphism. However, it's worth nothing that amylopectin's short-branched chains are the predominant crystalline component of native starch granules, whilst amylose and amylopectin's branching chain create amorphous regions. The partial crystallinity of natural starch granules is thus due to an structure of amylopectin side chains aggregated together. The amylose and amylopectin ratio of the starch is determined by its source, age, and the extraction procedure used (Jawaid & Swain, 2017). The starch structure of amylose and amylopectin are shown in Figure 2.9 and Figure 2.10. Meanwhile the segment for amylose and amylopectin molecule are shown in Figure 2.11 and Figure 2.12.

Figure 2.9 Starch amylose structure (Jawaid & Swain, 2017)**.**

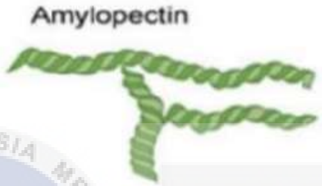


Figure 2.10 Starch amylopectin stucture (Jawaid & Swain, 2017)**.**

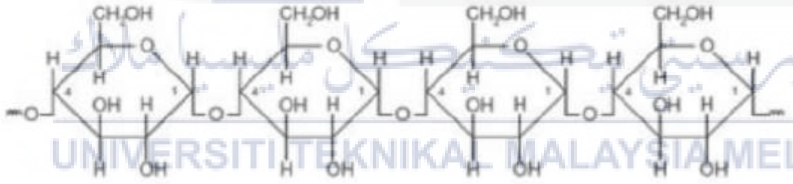


Figure 2.11 Segment of amylose molecule (Pérez-Pacheco et al., 2016)**.**

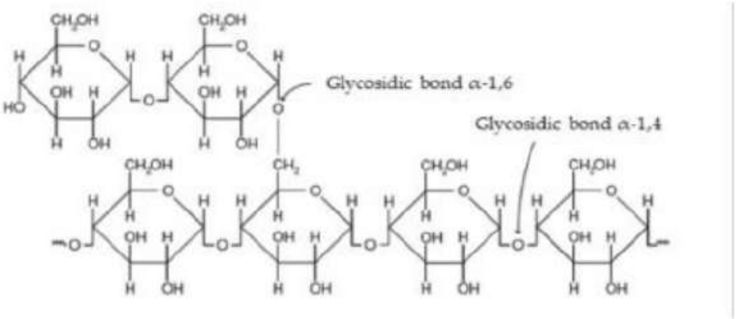


Figure 2.12 Segment of amylopectin molecule (Pérez-Pacheco et al., 2016)

However, other appealing properties of this material, like as its natural availability, biodegradability, low cost, and convenience of applying it to chemical modifications, have led to a variety of other uses (Guimarães et al., 2010). Starch is the least cost biopolymer among natural polymers, and it can be found in abundance in corn, potato, rice, and a variety of other natural sources. As a result, since the 1970s, starch has been employed in the plastic industry to create biodegradable plastic materials (Ruhul Amin et al., 2020). The basic structure of the starch molecule is shown in Figure 2.13.

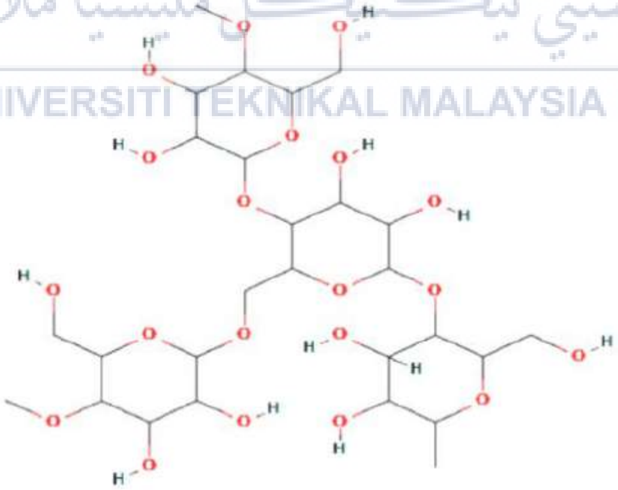


Figure 2.13 Basic structure of the starch molecule (Palanisamy et al., 2020)

2.3.2 Type of starch

The starch has generated a lot of interest as a potential packaging alternative to typical plastics. Some researchers have investigated the development and characterization of starch-based films made from cassava, sago, agar, sugar palm and many more. All these starches are potential biopolymer material for making biodegradable films (Sanyang et al., 2015).

Compared to other types of starch, cassava starch, also known as Manihot esculenta, contributes the most to productivity yield. Cassava is expected to have a yield potential of up to 17,000 kg of starch per hectare per year if maintained in a suitable location using organized farming technique (Ridhwan Jumaidin et al., 2020).

The Arenga Pinnata or usually known as sugar palm is a multipurpose tree that could be found in almost every tropical country. Almost every part of the tree is used to make local products like ropes, brushes, brooms, mats, cushions, palm wine, neera syrup, vinegar, and many others (Ilyas et al., 2019).

Sago palm (Metroxylone sagu) is a tropical South East Asian plant that is native to Malaysia, Indonesia, Papua New Guinea and Thailand. It has been an essential source of carbohydrate for the native population since prehistoric times. The sago palm is the starch-producing crop with the largest production, with up to 25 tonnes of starch per hectare each year. In term of yield per unit area, it could be three to four times higher than rice, corn, or wheat, and 17 times higher than cassava (Azmi et al., 2017). Table 2.2 shows the concentration of various starch sources of amylose and amylopectin.

Table 2.2 Amylose and amylopectin concentration of various starch sources (Marichelvam et al., 2019).

Source	Amylose (in %)	Amylopectin (in %)
Arrowroot	20.5	79.5
Banana	17	83
Cassava	18.6	81.4
Corn	28	72
Potato	17.8	82.2
Rice	35	65
Tapioca	16.7	83.3
Wheat	20	80

2.3.3 Corn starch

Corn is one of the most abundant sources of plant residue, offering a number of advantages such as high starch levels, outstanding uniformity, performance, ease of availability, and biodegradability (Hazrol et al., 2021). Corn starch contributes for about 80 percent of the world's starch market. This starch is an important ingredient in the foodservice industry because of its excellent phycochemical and techno-functional characteristics, and it is commonly used as a thickener, stabilizer, textural modifier, gelling, bulking, and water retention agent in food formulations (Mir et al., 2017).

A little amount of protein (0.35 percent), fat (0.8 percent), ash, and >98 percent of two polysaccharides, which is amylose and amylopectin, are discovered in basic corn starches. Corn and waxy maize starch granules usually range in size from 2 to 3 mm, with the majority occurring between 12 and 15 mm. They also differ in shape, appearing as polygon cross-sections (Palanisamy et al., 2020). Table 2.3 below shows the physical and chemical properties of corn starch.

Table 2.3 Physical and chemical properties of corn starch (Marichelvam et al., 2019)**.**

Properties	Corn starch
Moisture content (in %)	10.82
Ash content (in %)	0.32
Protein (in %)	0.38
Fat (in %)	0.32
Fiber (in %)	0.10
Amylose (in %)	29.4
Density (g/ml)	1.356
pH	6.72

2.3.4 Advantages and disadvantages

One of the advantages of starch is that, after cellulose, it is regarded as the second most important renewable resources. It is both affordable and totally biodegradable, which has generated a lot of interest in using it as a bioplastic component. Starch is a versatile material since it can be transformed into chemicals like ethanol, acetone, and organic acids utilised in synthetic polymer manufacturing, such as polylactic acid (PLA), as well as thermoplastic (TPS) with the help of a plasticizer at shear temperature conditions. Then, the colour of pure starch is white. It's a tasteless, odourless powder that's one of the most common natural polysaccharides synthesized from plants, with global starch output exceeding 50 million tonnes per year (Diyana, Jumaidin, Selamat, Ghazali, et al., 2021).

Meanwhile, due to some limitations, biodegradable polymer cannot be used in a wide range of applications. When compared to typical thermoplastics, starch-based biodegradable products reveal some disadvantages, which can be related to starch's highly hydrophilic characteristic. Strong hydrogen bonds normally hold the starch chains together, leading starch granules to be insoluble in cold water. When starch is turned into thermoplastic, the crystalline structure is damaged, allowing water molecules to interact with hydroxyl groups and producing partial solubilization of the starch granules. Because of starch's hydrophilic nature, it has a low water stability and a high moisture sensitivity, limiting the development of starch-based materials (Ridhwan Jumaidin et al., 2017).

2.4 Plasticizer

2.4.1 Introduction of plasticizer

Plasticizers are one of the most important additives required in the processing of polymer materials, especially polyvinyl chloride (PVC) plastics. This source accounts for more than 60% of total plastic auxiliary yield. Traditional petroleum-based phthalate plasticizers used to account for a large portion of total plasticizer production and sales, but they have gradually been phased out due to potential health and environmental risks. Green plasticizers that are non-toxic and have excellent performance, oil resistance, extraction, and migration resistance are constantly being developed, manufactured, and used in electrical insulation, food packaging, and medical and health products. Plasticizers are functional additives that improve the flexibility, plasticity, processability, and elongation of polymers, most notably in PVC products. Plasticizers are most commonly used to increase polymer flexibility and elongation while decreasing hardness, softening temperature, elastic modulus, and embrittlement temperature. Non-phthalate plasticizers include citric acid ester, phosphates, polyesters, halogenated alkanes, and epoxy compounds. Global hygienic requirements for plastic additives are increasing as people become more aware of environmental protection issues, particularly the discovery of potential risks to human health posed by phthalate plasticizers and ecological pollution issues (Jia et al., 2018).

2.4.2 Type of plasticizer

Plasticization can be categorized into two techniques which are external and internal. External plasticization is a physical mixing procedure that provides plasticity. External plasticizers are not chemically bonded to the polymer. Therefore, they can evaporate, migrate, or extrude from polymer products. Internal plasticization is the process of incorporating comonomers into polymers or reacting with them to create flexible chain units. Internal plasticizers are the group (flexible segment) that are part of a basic polymer chain and can be grafted as side chains or integrated regularly or irregularly between inflexible monomers (hard segments) to reduce intermolecular forces (Wojciechowska, 2012).

Plasticizers are classified as primary or secondary based on their solubility in highly concentrated polymers. It is referred to as a plasticizer if it is soluble and capable of fast gelling the polymer at standard processing temperature. Secondary plasticizers, on the other hand, have lower gelation capabilities and are typically combined with main plasticizers to improve product qualities or reduce cost (Nur Hanani et al., 2013).

The most typical plasticizer used for starch-based films are polyols such as sorbitol and glycerol, amongst many others. Several studies have been carried out to identify how polyols (particularly glycerol and sorbitol) affect the characteristics of films made from several starch origins (Sanyang et al., 2015). To create a deformable thermoplastic material called Thermoplastic starch, a plasticizer such as urea, glycerol, sorbitol, glycerin, and water is required (TPS) (Khan et al., 2017).

2.4.3 Glycerol

Glycerol is a valuable by-product produced in a variety of methods and by a variety of industries. Glycerol, also called glycerine or propane-1,2,3-triol, is a chemical with a wide range of applications in the pharmaceutical, cosmetics, and food industries.

Glycerol is some kind of organic substance with the formula $C_3H_8O_3$. Glycerine, Propane-1,2,3-triol, 1,2,3-propanetril, 1,2,3-trihydroxypropane, glyceritol, and glycyl alcohol are all synonyms for it. Glycerol is a low-toxicity alcohol made composed of three carbon chains, each having a hydroxyl group attached. It is derived from natural or petrochemical feedstocks. Glycerol is virtually non-toxic to humans and the environment. Glycerol is a liquid that is transparent, colourless, odourless, hygroscopic, vicious, and tasted sweet (Tan et al., 2013). Figure 2.14 shows the chemical structure of glycerol.

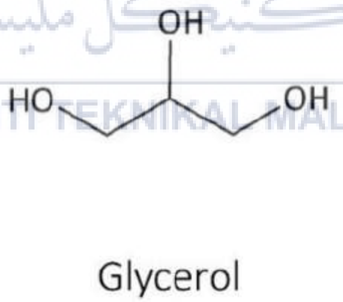


Figure 2.14 Chemical structure of Glycerol (González et al., 2020)

2.4.4 Advantages and disadvantages

The benefits of plasticizer include improved workability and reduced film brittleness when added to pure starch. Furthermore, when multiple plasticizers are used in a film matrix, strong interactions between the plasticizers can occur (plasticizer-plasticizer interactions), which can improve certain functional properties of the film (Sanyang et al., 2015). This latter option refers to the development of natural-based plasticizers, which has recently sparked interest in academic and industrial research. The use of such plasticizers, which are low in toxicity and have good compatibility with a variety of plastics, resins, rubber, and elastomers, to replace conventional synthetic plasticizers is becoming more appealing (Hazrati et al., 2021). Aside from that, the plasticizer should be natural, inexpensive, and renewable in order to make the process both cost effective and biodegradable (Khan et al., 2017). The benefits of using a plasticizer include increased elongation, softness, solvency, surface lubricity, decreased viscosity, improved thermal stability, and flexibility (Hazrol et al., 2021).

However, plasticizers have their own limitations, such as the formation of discontinuity zones during film dying due to phase separation caused by water insoluble plasticizers. As a result, the rates of water vapour permeability increase. An optimum stirring rate of the polymetric dispersion with the plasticizer can achieve complete uptake of the insoluble plasticizer by the polymer (Vieira et al., 2011).

2.5 Previous result

2.5.1 Moisture content and water solubility testing

Based on study by Ibrahim et al., (2019), the result for moisture content and water solubility testing were regardless of plasticizer type, increasing the plasticizer concentration from 25% to 40%, then to 55%, increases the water retention of plasticized films that rely on the plasticizers' ability to hold water. The effect of urea on the moisture content of corn starch films, on the other hand, was more prevalent than that of fructose and sorbitol-plasticized films. The difference in water retention of plasticized films was attributed to the resemblance of glucose units in the plasticizers' molecular structure, with the lower resemblance of glucose units causing a weak molecular interaction between the plasticizer and the intermolecular of biopolymer chains. As a result, the plasticizer's ability to interact with water molecules increased. The water solubility of the starch-based film is an important feature property for applications that may require water insolubility to improve water resistance and product integrity. As a result of the plasticizers' hydrophilic nature, both the type and concentration of plasticizer had a strong influence on the water solubility of corn starch films. The addition of plasticizers reduces interactions between polymer molecules, resulting in more free space in the structure of the polymer chain. This, in turn, allows water fragments to penetrate the film matrix, maximizing plasticized film solubility (Ibrahim et al., 2019).

2.5.2 Soil burial testing

Next is soil burial testing. The result is based on a previous study by Azahari et al., (2011). Figure 2.15 and Figure 2.16 show the weight loss of pure PVOH and PVOH/CS, respectively. Soil and compost films, respectively. According to the figures, as the burial time increased in both the soil and compost for eight weeks, the biodegradability increased up to 85 percent. In the first seven days, all of the films in the soil and compost degraded rapidly. This rapid degradation was caused by the composting process, which consisted of two major stages: active composting and curing. The temperature rose and remained elevated in the first stage as long as there was available oxygen, resulting in intense microbial activity. The weight loss of PVOH/CS films after eight weeks in the soil is shown in figure Figure 2.15.

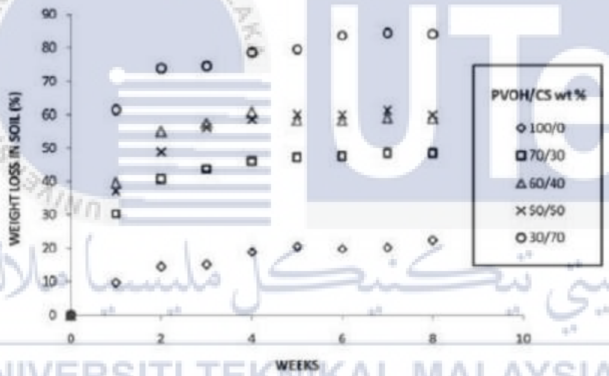


Figure 2.15 Weight loss of PVOH/CS films after eight weeks in soil (Azahari et al., 2011)

The temperature dropped in the second stage, but the film continued to compost at a slower rate. The 30/70 PVOH/CS sample showed the most significant weight loss in both soil and compost, while pure PVOH showed the most minor weight loss over time. This finding was attributed to the film's corn starch content, which is more biodegradable than pure PVOH. Because of its high hydrolysability, PVOH is biodegradable and has a higher resistance to soil burial degradation. The addition of compost increased the degradation rate by approximately 2–3 percent. Compost is made up of organic materials derived from decomposed plant and animal matter.

Aerobic decomposition was used to decompose the majority of the material. It may be nutrient-dense. The compost itself is beneficial to the land in a variety of ways, as it can act as a soil conditioner, a fertiliser, a source of vital humus or humic acids, and a natural pesticide for the soil. The nutrients in compost can degrade the film faster than unaltered soil.

As shown in Figure 2.16, the weight loss was slightly lower for the duration of 14 to 30 days, but the composting process did not come to a halt at any point. Instead, it proceeded slowly until the last remaining nutrients were consumed by the remaining microorganisms and nearly all of the carbon was converted to carbon dioxide. For the result of weight loss of PVOH/CS films after eight weeks in the compost is shown in Figure 2.16 below.

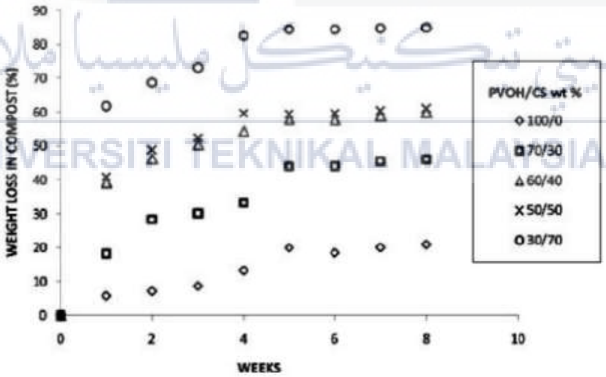
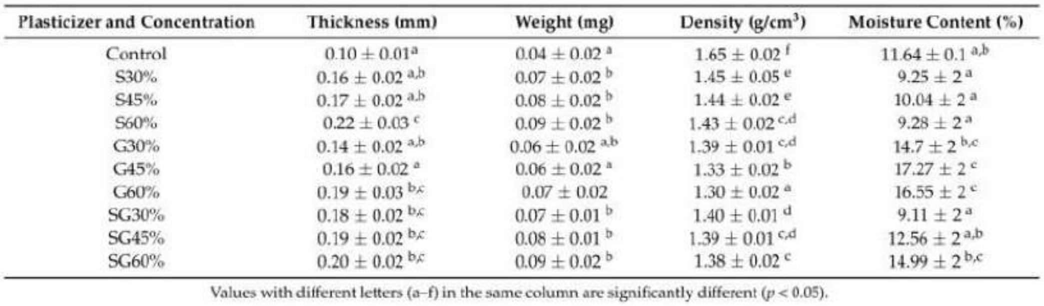


Figure 2.16 Weight loss of PVOH/CS films after eight weeks in the compost (Azahari et al., 2011)

2.5.3 Density testing

For density testing, the result is based on (Hazrol et al., 2021), according to table in Figure 2.17, adding plasticizers reduced the density of corn starch from 1.65 g/cm3 to 0.65 g/cm3. As a result, the plasticized corn starch films were less dense than the unplasticized corn starch film. Table in Figure 2.17 shows the effect of plasticizer types and concentrations on the density of corn starch films. Raising the plasticizer concentration from 30% to 60% resulted in slight decreases in the density of S- (1.45–1.43 g/cm3), G- (1.39–1.30 g/cm3), and SG-plasticized films (1.40–1.38 g/cm3). It can be demonstrated that increasing the percentage of plasticizers from 30% to 60% reduced film density marginally regardless of plasticizer type. The plasticized films S, G, and SG produced results that were consistent with those obtained from Hazrol et al., (2021), a dry treatment technique (hot pressing) is used to plasticize sugar palm starch with glycerol (15, 30, and 45 percent). The density values revealed no distinction between the various types of plasticizers. However, in decreasing order of density, S, SG, and G plasticized films with the same plasticizer concentration are used. This phenomenon could explain the difference in molecular weight and density of plasticizers. In the Figure 2.17 below shows the table of physical properties of corn starch films incorporated with various plasticizer types and concentration.



Plasticizer and Concentration	Thickness (mm)	Weight (mg)	Density (g/cm^3)	Moisture Content (%)
Control	0.10 ± 0.01^{a}	0.04 ± 0.02^{a}	1.65 ± 0.02^{f}	11.64 ± 0.1^{a,b}
S30%	0.16 ± 0.02^{a,b}	0.07 ± 0.02^{b}	1.45 ± 0.05^{e}	9.25 ± 2^{a}
S45%	0.17 ± 0.02^{a,b}	0.08 ± 0.02^{b}	1.44 ± 0.02^{e}	10.04 ± 2^{a}
S60%	0.22 ± 0.03^{c}	0.09 ± 0.02^{b}	1.43 ± 0.02^{c,d}	9.28 ± 2^{a}
G30%	0.14 ± 0.02^{a,b}	0.06 ± 0.02^{a,b}	1.39 ± 0.01^{c,d}	14.7 ± 2^{b,c}
G45%	0.16 ± 0.02^{a}	0.06 ± 0.02^{a}	1.33 ± 0.02^{b}	17.27 ± 2^{c}
G60%	0.19 ± 0.03^{b,c}	0.07 ± 0.02	1.30 ± 0.02^{a}	16.55 ± 2^{c}
SG30%	0.18 ± 0.02^{b,c}	0.07 ± 0.01^{b}	1.40 ± 0.01^{d}	9.11 ± 2^{a}
SG45%	0.19 ± 0.02^{b,c}	0.08 ± 0.01^{b}	1.39 ± 0.01^{c,d}	12.56 ± 2^{a,b}
SG60%	0.20 ± 0.02^{b,c}	0.09 ± 0.02^{b}	1.38 ± 0.02^{c}	14.99 ± 2^{b,c}

Values with different letters (a–f) in the same column are significantly different ($p < 0.05$).

Figure 2.17 The table of physical properties of corn starch films incorporated with various plasticizer types and concentration (Hazrol et al., 2021).

2.5.4 Water absorption testing

For water absorption testing, Figure 2.18, Figure 2.19, and Figure 2.20 show the percentage of weight gain for the corn starch-plasticized film based on water intake. Water absorption is important for starch films because it acts as a plasticizer. Plasticized films with a higher plasticizer and moisture content were more flexible. The immersion time was limited to 160 minutes because the film samples began to dissolve in water at 140 minutes due to the high hydrophilicity of plasticized films with higher plasticizer content. The formation of hydrogen bonds with starch caused by the presence of hydroxyl groups within the plasticizer molecules resulted in a higher tendency of water absorption into plasticized polymers.

Figure 2.18, Figure 2.19, and Figure 2.20 show the water absorption percentage as a function of time for corn starch films with various types of plasticizer and material. Surprisingly, both films absorbed a large volume of water at room temperature during the first 20 minutes of immersion. Because of their water-soluble and naturally hygroscopic properties, higher plasticizer content improved the films' water absorption. The control film absorbed approximately 120 percent in 40 minutes, whereas the S-, G-, and SG-plasticized films absorbed approximately 147 percent, 112 percent, and 135 percent of the plasticized films, respectively. Except for the 60 percent glycerol-plasticized film, the control film and all films with different plasticizer types and content began to dissolve in water after 140 minutes. For the result, it is shown in Figure 2.18, Figure 2.19 and Figure 2.20.

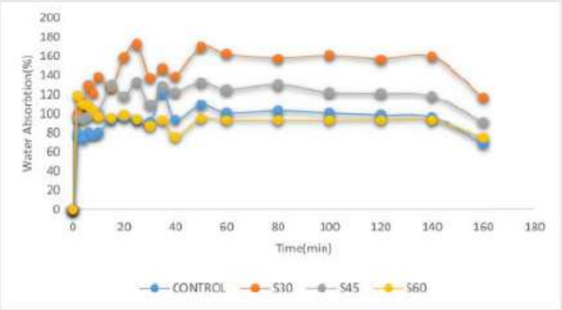


Figure 2.18 Water absorption on corn starch films with sorbitol plasticizer (Hazrol et al., 2021).

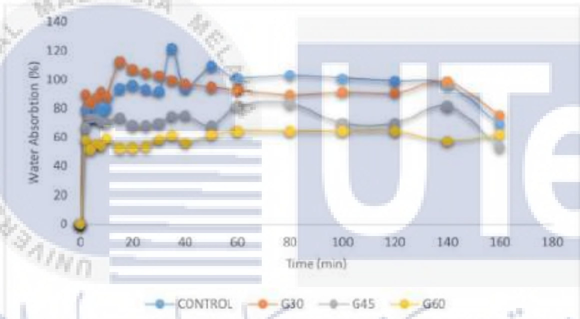
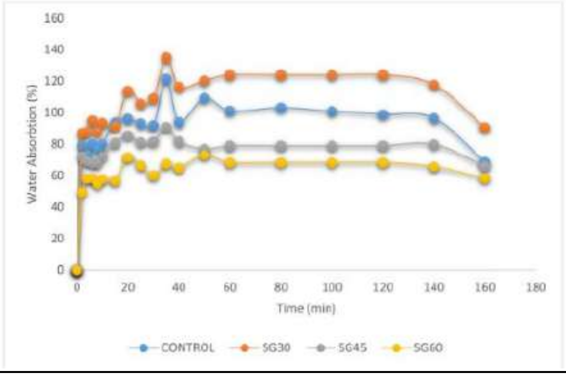


Figure 2.19 Water absorption on corn starch films with glycerol plasticizer (Hazrol et al., 2021).

Figure 2.20 Water absorption on corn starch films with sorbitol/glycerol plasticizer (Hazrol et al., 2021)

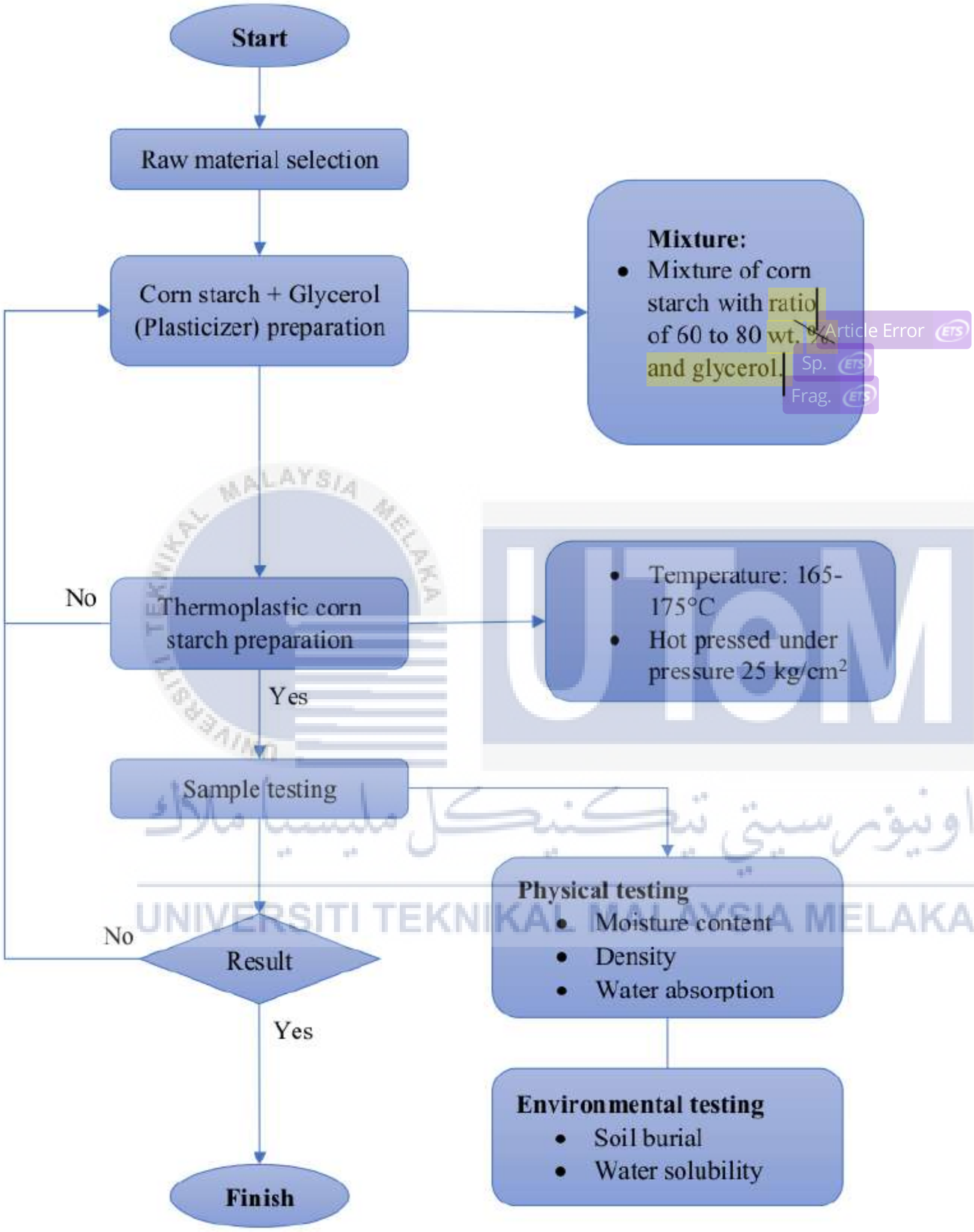


CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter introduces the methodology that has been discussed, and it will be carrying out in this project development as planned. This chapter includes the processes based on the scope of this project, the flow charts of the process to make sure that this project will be done on time in order to complete this project. The methods that will be used in this project is physical method which are moisture content, density and water absorption testing and environmental method which are soil burial testing and water solubility.



3.2 Flow chart

Figure 3.1 Flow chart of the process

3.3 Raw material

The natural material that has been choose for this study is corn starch, due to its unique functional properties, lack of odour, low cost, and quality, corn starch is widely used in processed foods, pharmaceuticals, textiles and paper products among others (Abotbina et al., 2020). The corn starch were purchased from Polyscientific Enterprise Sdn. Bhd. Then, the next material that need to prepare for fabricate the matrix sample is plasticizer, which is glycerol. The glycerol was produced by Qrec Chemicals, also purchased from the same supplier as the corn starch.

Figure 3.2 Corn starch

Figure 3.3 Glycerol

Table 3.1 Glycerol material specification

Specification	**Composition**
Assay (acidimetric)	Min. 99.5%
Insoluble in water	Passes test
Acidty/alkalinity	Passes test
Halogen Compounds (as Cl)	Max. 0.003%
Chloride (Cl)	Max. 0.001%
Sulfates (SO_4)	Max. 0.001%
Ammonium (NH_4)	Max. 0.0015%
Arsenic (As)	Max. 0.0001%
Copper (Cu)	Max. 0.001%
Heavy Metals (as Pb)	Max. 0.0005%
Iron (Fe)	Max. 0.0005%
Lead (Pb)	Max. 0.001%
Nickle (Ni)	Max. 0.0005%
Zinc (Zn)	Max. 0.001%
Aldehydes (HCHO)	Max. 0.0005%
1,2,4-butantriol (G.C)	Max. 0.2%
Sulfated Ash	Max. 0.01%
Water	Max. 2%

3.4 Material preparation

Before beginning the testing, we must prepare the sample first. The sample is made of a mixture of corn starch and a plasticizer which is glycerol. For the mixture, hand mixed manually the corn starch and glycerol first before mixing using blender for two to three minutes. Then put the mixed material into the mold with the size of 140 x 60 mm, before press it in hot press machine under 25 kg/cm^2 pressure. Before proceeding to hot press process, pre-heat the mold in the machine first for 15 minutes with temperature 165°C. After that, hot press the mold for 15 minutes with the same temperature then cooling process also for 15 minutes. Next, take out the sample from mold by using 10 tons press machine and the sample is ready to be cut by using cutting machine.

Figure 3.4 Mild Steel Mould

Figure 3.5 Mould Description

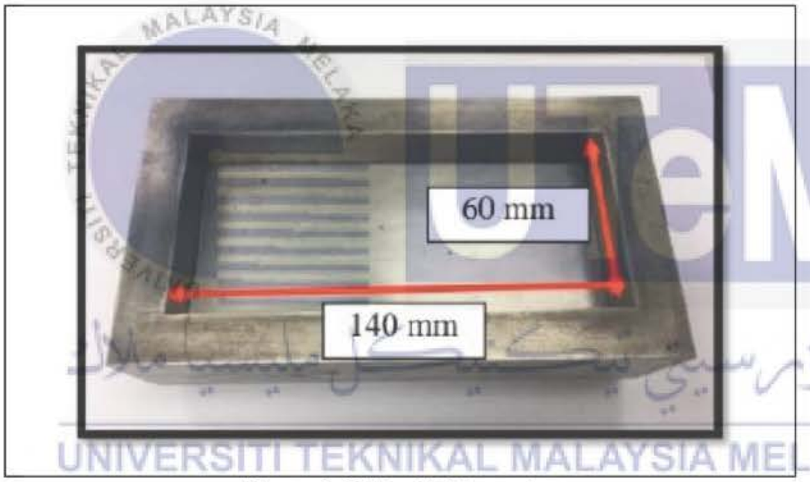


Figure 3.6 Mould Dimension

Figure 3.8 Hot Press Machine

Figure 3.7 De-mold machine

Figure 3.9 Cutting Machine

Figure 3.10 Digital scale

Figure 3.11 Blender

Figure 3.13 Oven

Figure 3.12 Sample dimension

Weigh the corn starch according to ratio by using digital scale.

Weigh the glycerol according to ratio by using digital scale.

Put weighed corn starch and glycerol together in the container.

Mixed corn starch and glycerol manually by hands.

Dry mixing the material by using blender for 2-3 minutes.

Put the blended material in the prepared mould.

Close the mould tightly and carefully.

Hot press the mould for 15 minutes then curing for 15 minutes by using Hot Press Machine.

After curing process, de-mould by using press machine to take out the sample.

The cutted sample is ready for testing.

Cut the sample according to testing standard by using cutting machine.

Cured of corn starch and glycerol mixture.

Figure 3.14 Fabrication of thermoplastic corn starch in flow chart form

3.5 Physical testing

3.5.1 Moisture content

According to the previous study Jumaidin et al., (2017), for moisture content, the sample (10 x 10 mm) were prepared for the moisture content investigation. All the samples were dried in an oven for 24 h at 105 ºC. Weight of samples, before (M_i) and after (M_f) the heating was measured in order to calculate moisture content. The moisture content was determined by using Equation 3.1. The test were conducted in a few replications and the average value was computed.

$$\text{Moisture content (\%)} = \frac{M_i - M_f}{M_i} \text{x} 100 \qquad 3.1$$

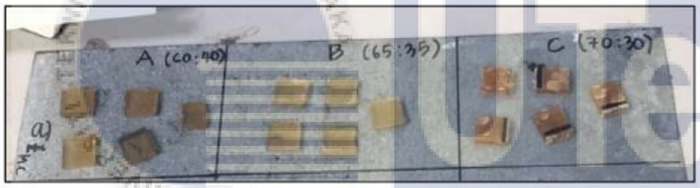


Figure 3.15 Samples for Moisture Content after dried in oven

3.5.2 Density

Based on the previous study, (Zuraida et al., 2012), the density testing of thermoplastic corn starch was carried out with the use of a high-precision electronic balance, densimeter, MD-300S model. By using Equation 3.2 below for density measurement.

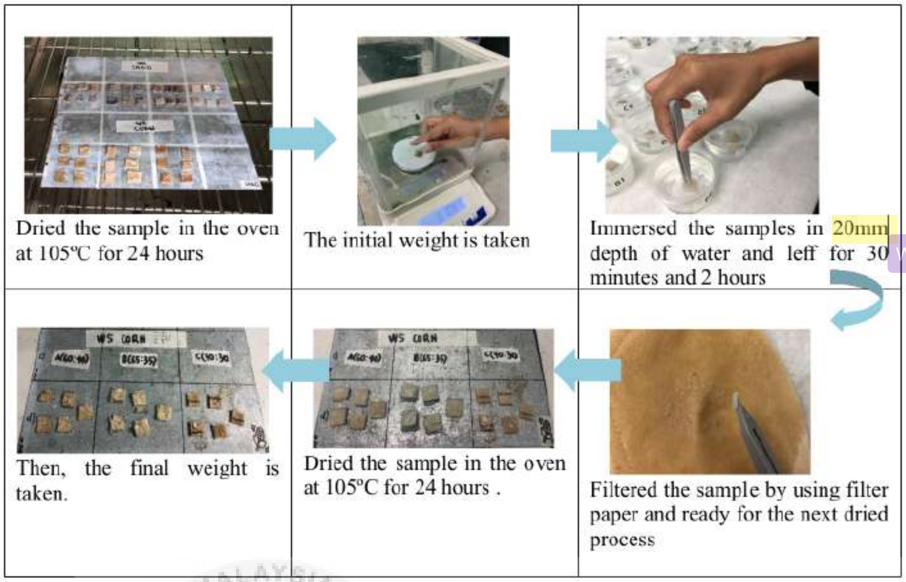
$$\rho = \frac{m}{v} \qquad 3.2$$

Figure 3.16 Electronic Densimeter

3.5.3 Water absorption

Based on the study of Jumaidin et al., (2017), specimens having dimensions of 10 x 10 mm x 3 mm were dried in an air circulating oven at 105 ºC ± 2 for 24 h to remove existing moisture, followed by immersing in water at room temperature (23 ± 1 ºC) for 0.5, 2 and 24 h, respectively, as mentioned in some previous studies (Lomelí Ramírez et al., 2011; Sahari et al., 2012). The samples were weighed before (W_i) and after immersion (W_f) and water absorption of the laminates was calculated using Equation 3.3. The test was conducted in a few replications and the average value was computed.

$$\text{Water absorption (\%)} = \frac{W_f - W_i}{W_i} \text{x } 100 \qquad 3.3$$



Dried the sample in the oven at 105ºC for 24 hours

The initial weight is taken

Immersed the samples in 20mm depth of water and left for 30 minutes and 2 hours

Filtered the sample by using filter paper and ready for the next dried process

Dried the sample in the oven at 105ºC for 24 hours .

Then, the final weight is taken.

Figure 3.17 Water absorption testing

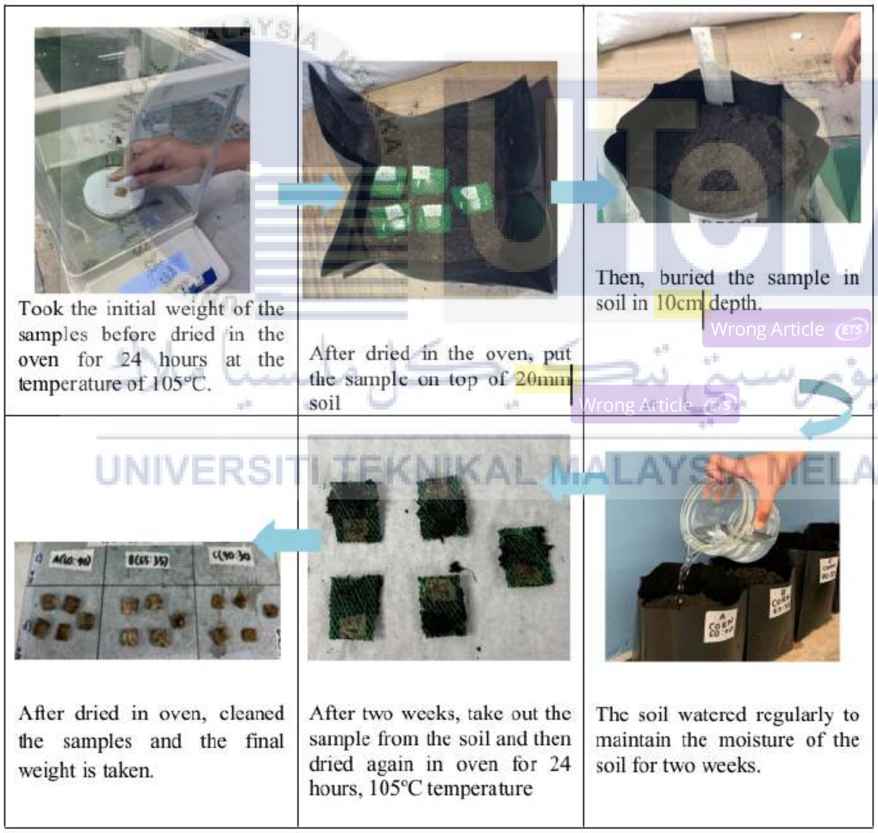
3.6 Environmental testing

3.6.1 Soil burial

For this testing, five samples (10 x 10 x 3 mm) for each ratio, were buried at 10 cm depth in soil which was regularly moistened with distilled water. The average environmental temperature and relative humidity (RH) for the testing is 26±4 °C and 76±4% RH, the ph of the soil is 6.5, and the moisture content is 28±8%. PVC net was used up to wrap the samples before burying into the soil to facilitate removal of the degraded samples while maintaining the access of moisture and microorganism.

Prior to testing, samples were dried at 105 °C for 24 h and weighed to obtain the initial weight, W_i. Two sets of experiments were carried out at two-week and four-week intervals. At predetermined intervals, soil samples were collected and gently cleaned with distilled water to remove impurities. Afterwards, they were dried at 105°C for 24 hr and weighed to obtain the final weight, W_f. The weight loss of samples was determined using Equation 3.3. The procedure was followed as the previous study (Ridhwan Jumaidin et al., 2020).

$$\text{Weight loss (\%)} = \frac{W_f - W_i}{W_i} \quad \text{x } 100 \qquad \textbf{3.4}$$



Took the initial weight of the samples before dried in the oven for 24 hours at the temperature of 105°C.

After dried in the oven, put the sample on top of 20mm soil

Then, buried the sample in soil in 10cm depth.

The soil watered regularly to maintain the moisture of the soil for two weeks.

After two weeks, take out the sample from the soil and then dried again in oven for 24 hours, 105°C temperature

After dried in oven, cleaned the samples and the final weight is taken.

Figure 3.18 Soil Burial testing

3.6.2 Water solubility

Water solubility (WS) of the samples is determined according to the previous method from Jumaidin et al., 2017), with a slight modification. For this, piece of sample (10 mm x 10mm x 3 mm) was cut and dried at 150 °C ± 2 for 24 hr. The initial weight of samples (W_o) was measured before immersing into 30 mL of distilled water with gentle stirring. After 8 h of immersion, the remaining piece of sample, taken from the beaker and filter paper, was used to remove the remaining water on the surface. Then, the sample was dried again at 150 °C ± 2 for 24 hr to determine the final weight (W_f). The water solubility of the sample was calculated by using Equation 3.4. The test was conducted in a few replications and the average value was computed (Jumaidin et al., 2017).

$$\text{Water solubility } (\%) = \frac{W_o - W_f}{W_o} \times 100 \qquad 3.5$$

After 24 hours dried in oven with 105°C temperature, take the initial weight of samples gently stirred before immersed for 24 hours in 20mm depth of water.	After immersed for 24 hours in 20mm depth water, the sample dried again in oven for 24 hours with the same temperature, 105°C.	Then, after dried 24 hours in oven, the final weight of the samples is taken.

Figure 3.19 Water Solubility samples testing

CHAPTER 4

RESULTS AND DISCUSSION

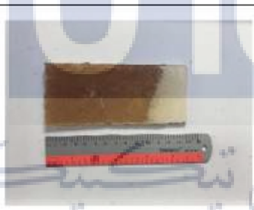
4.1 Introduction

This chapter will discuss the data and result that were drawn from the testing and observations that began on the first day of the experiment. Environmental tests, such as soil burial testing and water solubility testing, were used to evaluate the hypothesis on the influence of thermoplastic corn starch. Water absorption, density, and moisture content are the other three physical tests mentioned. Tables, graphs, and figures that indicate the outcome are displayed to demonstrate and make it more understandable.

4.2 Fabricated sample

Table 4.1 below shows the samples of corn starch mixed with glycerol with different ratios. The higher the content of starch, the less the sample is cooked. The condition of the sample that used 80 wt.% of starch is uncooked, also same goes to the sample that used 75 wt.% were partially overcooked or brittle and uncooked due to low content of glycerol. The samples from these two ratios cannot be used or are unsuitable to used for testing. As mentioned by (Zakaria et al., 2021), 20 wt.% and 25 wt.% of glycerol mixtures remained brittle and powdery. Meanwhile for 65 wt.% of corn starch, it is suitable to used for testing because (Zaaba & Ismail, 2020) stated that, the addition of glycerol as a plasticizer in more of 20% is enough to plastify the starch. Higher content of glycerol, on the other hand, soften the starch and cause it to become overplasticized.

Table 4.1 Samples of thermoplastic corn starch + glycerol with different ratio

Ratio	Figure of samples
60:40	
65:35	
70:30	
75:25	
80:20	

4.3 Physical testing

4.3.1 Density

The density of a material is an essential attribute to consider throughout the material selection process. This is because density may have an impact on the finished product's performance in a variety of ways, including weight, manufacturing and handling procedures, ease of use, transportation costs, and energy usage. It’s critical to look at the effects of the density of thermoplastic in order to see whether this biopolymer has the potential to replace non-biodegradable polymers (Jumaidin et al., 2017). For density testing, (Zuraida et al., 2012) had mentioned that the particle spacing is also represnted by the glycerol/starch ratio. Lowering the ratio resulted in tighter spacing between the starch particles, resulting in fewer voids and a denser material.

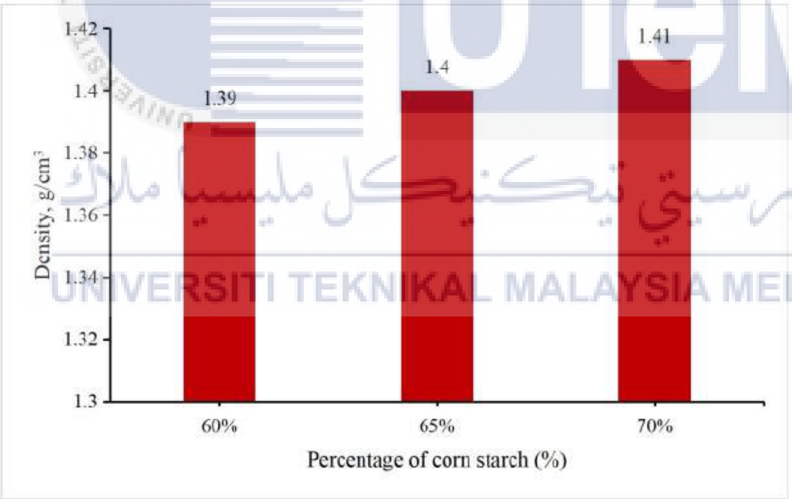


Figure 4.1 Density of Thermoplastic Corn Starch

The density of thermoplastic corn starch is shown in Figure 4.1. The densities of thermoplastic corn starch are 1.39 g/cm^3, 1.40g/cm^3, and 1.41g/cm^3 for 60, 65, and 70 wt% of corn starch compositions, respectively, according to Figure 4.1. The maximum density occurs at 70 wt% thermoplastics corn starch (1.41 g/cm^3), while the lowest density occurs at 60 wt% thermoplastics corn starch (1.39 g/cm^3). The difference in density decrease between the higher and lower density findings is roughly 0.02%. This demonstrated that when glycerol levels dropped, the density of thermoplastic corn starch increased linearly.

4.3.2 Water Absorption

Considering starch and agar are both polysachharides that are known to be moisture sensitive, it is crucial to investigate the water absorption capacity of the two materials in combination. Agar is made composed of agarose and agaropection, both of which are hydrophilic due to the creation of a bond between the hydroxyl group and the oxygen bond with water in starch. This is one of the primary reasons for thermoplastic starch and agar's hydrophilic behaviour (Jumaidin et al., 2017). The water absorption behaviour of thermoplastic corn starch has a significant impact on its dimensional stability (shelf life) and mechanical properties (Bergel et al., 2018). Water is known to be particularly sensitive to biopolymer compounds. As a result, it's crucial to look at the water absorption capabilities of the completely bio-based material developed in this research. A water absorption test is widely performed to determine how much water a material absorbs over a period of time (Ridhwan Jumaidin, Saidi, et al., 2019).

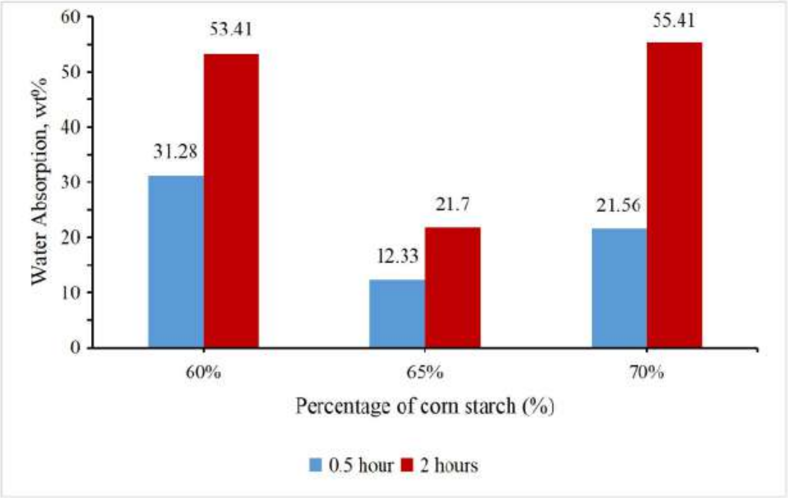


Figure 4.2 Water absorption of Thermoplastic corn starch

The findings of water absorption in two separate period of times which are 0.5-hour and 2 hours, are shown in the Figure 4.2. Only 12.33 wt% of corn starch was evaluated at 0.5 hours for a 65% content of corn starch composition. Meanwhile, with 60% corn starch content, the greatest rate of water absorption is 31.28 wt%. As for period of 2 hours, the result shows that 65% content of corn starch has the lowest water absorption compared to 60% and 70% corn starch content. The result is related to (Ridhwan Jumaidin, Saidi, et al., 2019), stated that the non-homogenous structure of the composites, which led to inconsistent water absorption behaviour, might be to responsible for the composites' fluctuating water absorption behaviour. As predicted, a 0.5-hour interval resulted in a lower rate of water absorption than a 2-hour period. Furthermore, the hydrophilic behaviour of thermoplastic might explain the increased water absorption as mentioned in previous study by (Zakaria et al., 2020).

4.3.3 Moisture Content

The equilibrium moisture content of thermoplastic was measured using moisture content. The moisture content of the material is an essential factor that may affect the end-dimensional product's stability. A prior research found that moisture content has a significant impact on material water absorption behaviour, with increased moisture content resulting in greater water absorption capacity (Jumaidin et al., 2017). Before evaluating a new possible natural material for polymer bio-composites, moisture content is a crucial aspect to examine. The stability of the bio-composite in terms of strength, dimensions, and porosity formation may be affected by high moisture content. As a result, the composite's low moisture content value is suitable for future exploration (Zakaria et al., 2020).

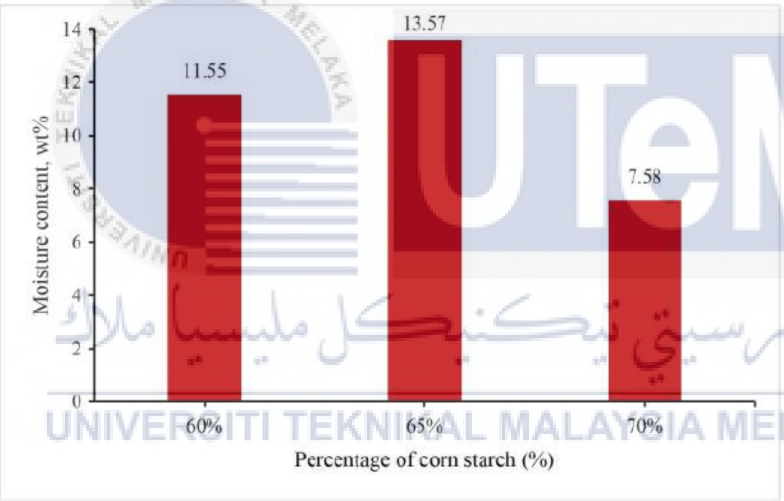


Figure 4.3 Moisture Content of Thermoplastic corn starch

The moisture content of a substance is defined as the amount of water that might be removed from it without affecting its chemical composition when compared to the material's base weight. As shown in Figure 4.3, corn starch with content of 65% and 60% had 13.57 wt% and 11.55 wt% whereas 70% of corn starch showed the lowest moisture content. This circumstances is related to study by (Zakaria et al., 2021) which stated that with additional plasticizer(glycerol), the combination of corn starch and glycerol becomes more hydrophilic. As a result, tests have shown that as greater plasticizers are added, the moisture content rises. Also, as mentioned by (Zuraida et al., 2012) about moisture content, this occur due to hydrophilic nature of starch and is proportional to the volume of spaces between starch particles.

4.4 Environmental Testing

4.4.1 Water Solubility

The term "water solubility" refers to a material's ability to resist water. Water solubility, in other hand, indicates how a substance degrades when immersed in water (R. Jumaidin et al., 2017). Also, there are certain drawbacks to thermoplastic starch, such as its higher water solubility. As a result, water solubility tests for matrix and composite materials should be analyzed and evaluated by determining the weight loss of the material after continuous stirring for a certain period of time (Jumaidin, Adam, et al., 2019). The solubilitiy of a bio-composite is an important paramenter since it reflects the product's integrity in an aqueous environment and also supports in the decision of the product's application (Diyana, Jumaidin, Selamat, & Suan, 2021)

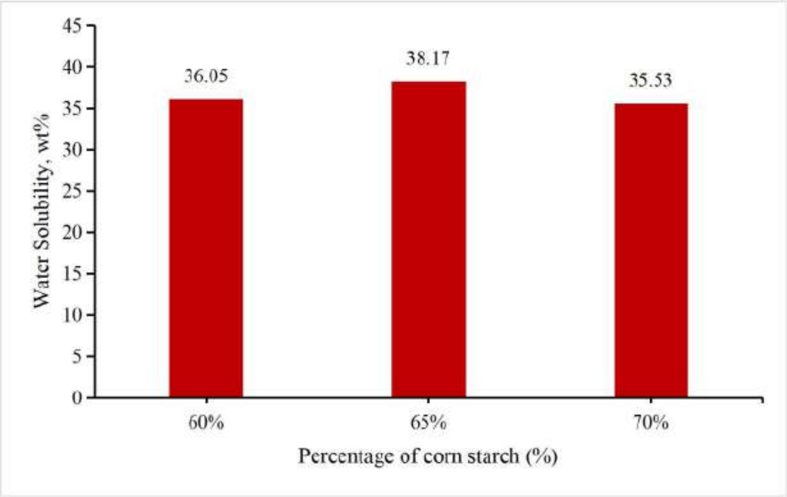


Figure 4.4 Water solubility of thermoplastic corn starch

Figure 4.4 shows the water solubility of thermoplastic corn starch, which reveals the materials' water resistance when immersed in water and continuously stirred. After immersed in water for 24 hours, the 60% of corn starch shows 36.05 wt% of water solubility. Meanwhile 38.17 wt% for 65% of corn starch which the highest too. Lastly for 70% of corn starch shows the lowest water solubility, 35.53 wt%. This circumstances can be compared to study by (Jumaidin, Saidi, et al., 2019) which stated that the lesser solubility of the composites compared to pure thermoplastic corn starch might be ascribed to the better water resistance of cogon grass fiber, which helps to prevent water absorption, which could lead to material breakdown and dissolving. This statement also supported by (Ridhwan Jumaidin, Adam, et al., 2019), specified that the abundance of free hydroxyl groups on the repeating unit of starch molecules in the thermoplastic potato starch matrix allows it to absorb more water, resulting in its hygroscopic nature. This data also indicates that the thermoplastic potato starch/sugarcane fiber composite is marginally more water resistant than the thermoplastic potato starch matrix. This might be influenced by the fact that fiber is less hygroscopic and more crystalline than starch.

4.4.2 Soil Burial

The weight loss due to moisture and microorganism activity during the soil burial phase can be used to estimate a material's biodegradation characteristic (Jumaidin et al., 2020). During the soil burial phase, the weight loss of the material can be used as a primary indicator of the biodegradation process by moisture and bacteria (Zakaria et al., 2020). Composites were tested in the soil to see if they degraded (Sapuan et al., 2013).

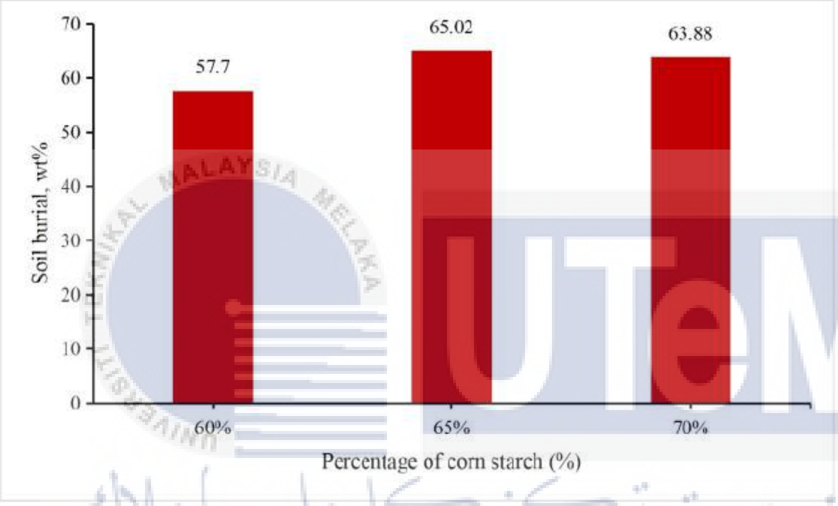


Figure 4.5 Soil Burial of thermoplastic corn starch

Figure 4.5 above shows the weight loss of thermoplastic corn starch after 2 weeks of soil burial testing. The weight loss of soil burial for 60% of corn starch is 57.70 wt%. Then 65.02 wt% for 65% of corn starch content, lastly 63.88 wt% for 70% of corn starch. It is obvious that the graph shows that 60% is the lowest and 65% is the highest weight loss. To be associated with this situation, (Azahari et al., 2011) mentioned that, since corn starch is more biodegradable than pure PVOH, this observation was attributed to the film's corn starch concentration. Along with its high hydrolysability, the PVOH is biodegradable and has a stronger resistance to soil burial degradation. Compost is made up of organic elements that have degraded mostly via aerobic decomposition. It might be a nutrient-dense food. Compost may operate as a soil conditionner, fertilizer, source of important humus or humic acids, and natural pesticide for soil, among other things. The nutrients in compost might speed up the desomposition of the film compared to unimproved soil.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The result of this project shows that thermoplastic corn starch it was successfully produced via blender and hot press after several time s of failed. A good compatibility between corn starch and glycerol which led to improvement in the properties of the material was revealed. From five ratios mixture of corn starch and glycerol, only three ratios are suitable to be tested. This is because the condition of last two thermoplastic ratios which are 75% and 80% content of corn starch is uncooked and brittle after the hot press process. In conclusion, thermoplastic corn starch already proved that it can be potential as alternative material for non-environmentally friendly plastic which biodegradable.

5.2 Recommendation

There are some recommendations provided to extend understanding of corn starch behaviour from this project, which are as follow:

- Suggest various type of plasticizers such as sorbitol, urea, fructose and other to investigate the behaviour and properties of corn starch.
- To increase the strength of thermoplastic. by adding multiple forms of plant fibers such as kenaf, banana leaf, pineapple leaf, bamboo, and others.
- To carry out the experiment early as possible so that can produce more thermoplastics corn starch so that enough to do other testing that require more sample for testing and have enough time to complete the project.

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Verb This verb may be incorrect. Proofread the sentence to make sure you have used the correct form of the verb.

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PAGE 51

Article Error You may need to use an article before this word.

Dup. You have typed two **identical words** in a row. You may need to delete one of them.

PAGE 52

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

PAGE 53

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

Article Error You may need to remove this article.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to remove this article.

Run-on This sentence may be a run-on sentence. Proofread it to see if it contains too many independent clauses or contains independent clauses that have been combined without conjunctions or punctuation. Look at the "Writer's Handbook" for advice about correcting run-on sentences.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Article Error You may need to use an article before this word.

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Article Error You may need to use an article before this word.

PAGE 55

Article Error You may need to use an article before this word. Consider using the article **the**.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

PAGE 56

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Article Error You may need to use an article before this word. Consider using the article **the**.

Article Error You may need to use an article before this word. Consider using the article **the**.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

PAGE 57

Article Error You may need to remove this article.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Missing "," You may need to place a comma after this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Missing "," You may need to place a comma after this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Prep. You may be using the wrong preposition.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Frag. This sentence may be a fragment or may have incorrect punctuation. Proofread the sentence to be sure that it has correct punctuation and that it has an independent clause with a complete subject and predicate.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

PAGE 60

Article Error You may need to use an article before this word.

Wrong Article You may have used the wrong article or pronoun. Proofread the sentence to make sure that the article or pronoun agrees with the word it describes.

Missing "," You may need to place a comma after this word.

Article Error You may need to use an article before this word. Consider using the article **the**.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

Article Error You may need to use an article before this word.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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Sentence Cap. Remember to capitalize the first word of each sentence.