

**EFFECT OF GLYCEROL AS PLASTICIZING
AGENT ON THE MECHANICAL PROPERTIES
OF POLYVINYL ALCOHOL/BANANA PEEL
POWDER BLEND FILM**

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MECHANICAL PROPERTIES OF POLYVINLYL ALCOHOL/BANANA
PEEL POWDER BLEND FILM**

TAN YEE LING

**A project report submitted in partial fulfilment of the
requirements for the award of
Bachelor of Engineering (Hons) Petrochemical Engineering**

**Faculty of Engineering and Green Technology
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January 2022

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

Nowadays, plastic pollution become more serious because the plastic bag that appear at the market is made from petroleum-based plastic which is difficult to degrade. Hence, biodegradable plastic is introduced to solve this serious problem. Polyvinyl alcohol (PVA) can blend with banana peel powder (BPP) to form a biodegradable film which can be degrade easily. Different composition of glycerol was added into the blend film to investigate the mechanical properties of the PVA/BPP blend film. PVA/BPP blend films were prepared by using solution casting method. The BPP and PVA/BPP blend film were analyse by using Attenuated Total Reflectance Spectroscopy (ATR), Thermogravimetric Analysis (TGA) and biodegradability test. Besides, the mechanical properties of PVA/BPP blend films were analyse by using tensile test which is to determine its tensile strength, elongation at break and Young's modulus. When increase the composition of glycerol, the tensile strength and Young's modulus of the blended film will decrease respectively. However, the elongation at break will increase as the composition of glycerol increase. The tensile strength and Young's modulus of PVA/BPP blend films that without glycerol (6.65MPa, 81.9MPa) will higher than the PVA/BPP blend film in the presence of glycerol (4.318MPa to 3.616MPa, 49.99MPa to 30.14MPa). Moreover, the elongation at break of the PVA/BPP blend film which contain glycerol (34.27% to 48.31%) is higher than PVA/BPP blend film that without glycerol (32.72%). After 2 weeks of biodegradability test, PVA/BPP blend films which contain 2ml of glycerol has the highest biodegradability rate (11.55%) among other PVA/BPP blend films.

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LIST OF SYMBOLS/ABBREVIATIONS

cm^{-1}	Centimetres
kg	Kilogram
ml	Millilitres
mm	Millimetres
MPa	MegaPascal
$wt\%$	Weight percentage
$\%$	Percentage
$^{\circ}C$	Degree Celsius (temperature unit)
ATR	Attenuated Total Reflectance Spectroscopy
BC	Bacterial cellulose
BP	Banana peel
BPP	Banana peel powder
BPW	Banana peel waste
CAGR	Compound annual growth rate
CNC	Cellulose nanocrystals
CNF	Cellulose nanofibrils
EDX	Energy Dispersive X-Ray
E&E	Electrical & Electronics
FESEM	Field Emission Scanning Electron Microscopy
F&B	Food & Beverages
JP	Jackfruit peel
JW	Jackfruit waste
MCC	Microcrystalline cellulose
MCO	Movement Control Order

MFC	Microfibrillated cellulose
OFAT	One- factor-at-a-time method
OPW	Orange peel waste
PHA	Polyhydroxyalkanoate
PLA	Polyactic acid
PSA	Particle Size Analysis
PVA	Polyvinyl alcohol
PVA/BPP	Polyvinyl alcohol/banana peel powder
PVA/CNF	Polyvinyl alcohol/cellulose nanofibrils
PVA/MCC	Polyvinyl alcohol/microcrystalline cellulose
PVA/MFC	Polyvinyl alcohol/microfibrillated cellulose
TGA	Thermogravimetric Analysis
TPS	Thermoplastic starch

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CHAPTER 1

INTRODUCTION

1.1 Background

Plastics are one of the famous versatile materials and it can be invented into a universal material that can be used in daily life. For example, plastics can be used as water bottles, household furniture, bumpers and more (Jansen, 2017). Plastics are famous to use because plastics have unique properties which are more flexible and plasticity compare with each other. Normally, plastics are synthetic and derived from the petrochemicals. In the other word, plastics are synthesis from polymers which contain carbon atoms, hydrogen, oxygen, sulphur, and nitrogen which can form a long chain molecule (Woodford, 2018). However, these may cause a lot of environment problems such as soil pollution or water pollution when the number of plastics is growing year by year. This will occur because some types of plastics need many years to decompose and some of the types are non-degradable as well. Therefore, bioplastics are introduced to overcome the problems that face by the plastics.

Bioplastics are wholly made from renewable biodegradable or biobased sources. Since bioplastics are made from renewable sources, thus it can degrade, recycle easily and the environmental problems can be reduced eventually. One of the type of bioplastics that contain biobased, and biodegradable is starch-based plastics. Starch can be found in potatoes, corn, bananas, or wheat. The limitations of the starch-based plastics are it has poor stability, brittleness, and moisture sensitivity when it compares with other synthetic plastics. Therefore, polyvinyl alcohol (PVA) is added into the starch-based plastics to improve the plastic performance (Ashter, 2016).

PVA is a synthetic polymer at the same time it also known as biodegradable polymer. Besides, PVA is biodegradable polymer and it can degrade easily by biological organisms. The reason of it is because of its degradability that can be improved through hydrolysis with the presence of hydroxyl groups on the carbon atoms. PVA are always blend with other polymer compounds such as polymers that contain hydrophilic properties and biopolymers. Various industrial applications are used PVA because it can improve the mechanical properties of films, compatible structure, and hydrophilic properties. When the PVA is mixed with other polymers, it showed an excellent compatibility with starch which can successfully reduce the brittleness and water uptake of starch-based plastics (Gaaz et al., 2015).

Cellulose is an organic compound which categories in polysaccharides. Cellulose is made up of thousands of D-glucose subunits. These thousand D-glucose subunits in cellulose are linked with the beta 1-4 glycosidic bonds (A Level Biology, 2020). Besides, cellulose is an unbranched molecule, and the polymeric chains of glucose are arranged in linear pattern. These chains are arranged parallel with each other unlike starch or glycogen. Normally, cellulose is synthesized in wood and plants. It also considered as the richest organic material and polysaccharide. Cellulose is important in biodegradable film due to its physical and mechanical properties. Furthermore, it is developed functionality, flexibility, and high specific strength due to the hierarchical structure. Other than that, the cellulose is also low density, cost effective, biodegradability, insoluble in water, high tensile strength and more. Furthermore, cellulose can be modified chemically by substituting the hydroxyl groups with functional group such as chlorides, oxides, and specific acids. Therefore, it is important for biodegradable film due to the chemical and physical properties of cellulose (Seddiqi et al., 2021).

Banana peel (BP) is rich in starch and cellulose which can make banana peel powder (BPP) as an ingredient for the production of biodegradable materials. Starch and cellulose nanofibres that served as film matrix and reinforcing agent can obtain from BPP. Cellulose nanofibres are isolated from lignocellulosic materials through 3 steps which are pretreatment, partial hydrolysis and mechanical disintegration of the raw material. Acid hydrolysis can used to break cellulose microfibers into nanofibres. Besides, cellulose nanofibres that obtained by acid hydrolysis have potential act as reinforcing agent in composites. However, the efficiency of the acid hydrolysis is

dependent on the concentration of acid. Sulphuric acid is preferable compare with other acid because it can generate more stable nanofibre with a negatively charged surface. Hence, it can prevent cellulose nanofibre agglomeration (Tibolla et al.).

Plasticizers is an additive that can be added into another material such as plastics to make them softer and more flexible compare with other. Besides, plasticizers can also use to control the viscosity, dispersion of particulates in polymer matrix or lubrication of compounds. Glycerol is one of the types of plasticizers. Glycerol is the main by-product of biodiesel production and corresponds to approximately 10% of the total biodiesel production. Glycerol can used as plasticizer to produce starch-based biodegradable films. Glycerol and starch are flow and melt at the temperature between 90°C and 180°C. It will produce thermoplastic starch under shear stress, and it also can produce through injection, extrusion and blowing equipment. Glycerol can create more flexibility in the polymer structure by reducing the intermolecular forces. Besides, glass transition temperature of material is reduced and enhanced the mobility of polymer chains in starch films and eventually it will increase the flexibility of the polymer structure (Bilck et al., 2015).

There are several types of mechanical properties must test such as tensile strength, elongation and toughness. Tensile strength is the maximum load that the polymer can accept before it breaks or permanent deformation (The Editors of Encyclopedia Britannica, 2017). When the molecular weight of the polymer increase, the tensile strength of polymer also increases. Generally, the tensile strength and molecular weight of the polymer are related to each other. In addition, elongation is the measurement of percentages that the length of polymer changes before it fractures. It can also measure the ductility of the polymer. The purpose of elongation is to test the resist changes of shape without cracking. Lastly, toughness also known as Young's modulus. Toughness is the measurement of energy that polymers can absorb before it breaks. Temperature is significantly affecting the mechanical properties of polymer. Therefore, the tensile strength and elastic modulus will decrease when the temperature increase.

In this study, PVA blend with BPP will be carry out by using solution casting method by manipulating the plasticizing agent composition and study effect of plasticizing agent which is glycerol.

1.2 Problem Statement

Plastic can be made by synthetic or biobased. Synthetic plastics are derived from petroleum based such as natural gas, crude oil, or coal. Nowadays, many synthetic plastics are used because it is easy to manufacture which involve the processing of crude oil (Baheti, 2017). The properties of synthetic plastics are inexpensive, lightweight, strong and corrosion resistant material (Thompson et al., 2009). A huge number of synthetic plastics are used due to these properties. Every year about 200 million tons of synthetic plastics are consumed in the planet (BioPak Team, 2019). As a consequence, the number of synthetic plastics used are keep increase because it does not handle well. The synthetic plastics are difficult to dispose, and this situation cause some environmental impact such as plastic pollution. Therefore, bioplastics are made to solve the environmental problem that created by synthetic plastics.

Bioplastic is different with synthetic plastic. Bioplastics are derived from renewable raw materials such as vegetable fats and oils, straw, recycled food waste, corn starch or more (BioPak Team, 2019). There are many types of bioplastics such as starch-based bioplastic, cellulose-based bioplastic, protein-based bioplastic, agro-waste based bioplastic or etc (The Basics of Bioplastics, 2018). Agro-wastes based bioplastics are derived from pineapple, lemon, banana peel, grape pomace, or tomato pomace. All the agro-waste based bioplastic are using the agriculture waste to proceed because it is cheap and available in significant quantities. Therefore, the agro-waste based bioplastic is preferable compare with other types of bioplastics (Maraveas, 2020). The bioplastics is preferable to use compare with synthetic plastic because the bioplastics is made from renewable raw materials and cause significantly less damage to the environment especially PVA. This is because PVA has good mechanical and thermal properties. In addition, PVA is also good in transparency and resistance to oxygen permeation.

BP is categorised under agro-waste based bioplastics and it is one of the common wastes which can replace the starch. This is because tonnes of BP are disposed to the environment and had led to a lot of environmental problems occurred.

In Malaysia, there are several industries that produce banana products such as banana cake, banana chips, banana fritters or etc. These industries use the banana flesh as a raw material and the peels are throw away at the end of the process. When BP are increase year by year, it can lead to health problems such as respiratory disorders and environmental problems such as soil pollution and global warming. BP can use as filler because it consists of high sources of starch and the glucose level increased when the BP ripen. If the BP too ripe, the starch will convert into glucose. Meanwhile, if the BP least ripe, it will become too firm although high in starch molecules. Hence, BP is a suitable waste material to produce bioplastics (Noor Fatimah Kader Sultan and Wan Lutfi Wan Johari, 2017).

The disadvantage of bioplastic without adding plasticizing agent is the mechanical strength is low. Hence, the bioplastics need to add plasticizing agent (Lusiana et al., 2019). The purpose of added plasticizing agent is to improve the properties of polymer. When the plasticizing agent presence, it helps in lower inelasticity of polymer and enhanced elongation of polymer to break at room temperature. Besides, it can also lower the temperature which substantial distortions and it able to achieve without needing enormous forces and increase the toughness of polymer to the lowest temperature of serviceability (Varee Tyagi, B. B., 2019). Glycerol is one of the plasticizing agents that used to produce starch-based biodegradable films. Glycerol and starch will melt and flow at temperature between 90°C to 180°C which under shear it readily followed by allowing it undergo blow equipment, extrusion, and injection (Yunos, 2011). Besides, plasticizing agent such as glycerol can create a greater flexibility in the polymer structure because the intermolecular forces and the glass transition temperature of the material will reduce. However, it will increase the mobility of the polymer chains in the starch films. Last but not least, addition of plasticizing agent which is glycerol can also improve the ability of bioplastic in absorbing water and act as a crystal forming agent (Bilck, A. P. *et al.*, 2015).

1.3 Aims and Objectives

The main purpose of this research project is to characterize the banana peel powder (BPP) and investigate the effect of glycerol on the mechanical properties of PVA/BPP blend films. The sub-objectives are as follows:

- i. To characterize the banana peel powder (BPP) and PVA/BPP blend film with different composition of glycerol.
- ii. To evaluate the effect of glycerol composition on the mechanical properties of PVA/BPP blend film.
- iii. To evaluate the effect of glycerol composition on the biodegradable properties of PVA/BPP blend film.

1.4 Scope of Study

There are the three scopes need to identify in this research to achieve the objectives. Firstly, the blending of PVA/BPP film was performed by using the solution casting method. Characteristics of BPP sample and PVA/BPP blend film were determined and analysed by using attenuated total reflectance spectroscopy (ATR) and thermogravimetric analysis (TGA).

Next, the composition of glycerol in blending of PVA/BPP film by using One-factor-at-a-time (OFAT) method is one of the parameter that need to be studied in this experiment. Other than that, mechanical characteristics of blended PVA/BPP film incorporate with glycerol was determined. The mechanical characteristics are tensile strength, elongation and Young's modulus. Lastly, the biodegradable characteristics of PVA/BPP blend film incorporate with glycerol also was determined.

CHAPTER 2

LITERATURE REVIEW

2.1 Plastics Industry in Malaysia

Plastics is the term that commonly used in our daily life. The common things that plastic can produce is T-shirt plastic bags. T-shirt plastic bag is very popular in Malaysia. This is because the benefits of plastics such as reusability, durability and portability (Plastic Supplier, 2018). All these benefits cause Malaysian like to use it. After the T-shirt plastic bag was damaged, it will be thrown away and this had caused the plastic wastes increase significantly day by day. Plastics can made from petroleum-based or biodegradable. Plastics can find in everywhere such as clothes, food packaging, medical equipment, toys and more. The **Figure 2.1** shows that the Malaysia plastic compounding market share in year 2015. From the **Figure 2.1**, the packaging segment is accounted for 28% market share in 2015 followed by automotive industries (Grand View Research, 2017).

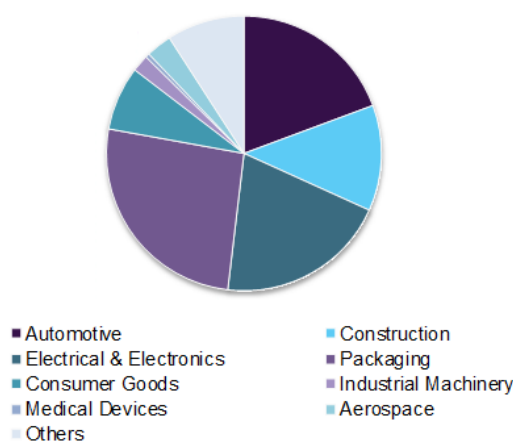


Figure 2.1: Malaysia Plastic Compounding Market Share in 2015 (Grand View Research, 2017).

There are a lot of plastic industry in Malaysia such as Toray Plastic Sdn Bhd, Lotte Chemical Titan Holding Berhad, Top Glove and etc. However, due to pandemic Covid-19, it had caused some impacts towards the sales of plastic industry in different sector. In overall, the sales in year 2020 had registered higher sales than the sales in year 2019. In year 2020, it had registered a sale of RM48.46 billion whereas the registered sales in year 2019 is around RM46.35 billion which had increased by 2.3%. The reason that caused plastic industry in Malaysia is less impacted by the pandemic Covid-19 but the sales get increased is because plastic industry act as a key supporting industry to essential sector such as Electrical & Electronics (E&E), Medical Supply, and Food & Beverages (F&B). Due to pandemic, people are mainly having to work from home, thus this scenario lead to strong demand in consumer electronics sector. For example, E&E sector have the production of TV sets in year 2020 had increased from 9.9 million units to 12.3 million units when compared to year 2019 which had increased by 24%. Besides, the air conditional production units for year 2020 also increased by 4% which is increased from 4.9 million units to 5.1 million units when compared to year 2019 (Boon, D. L. K., 2020).

However, automotive sector had negative impacts in production and sales by the pandemic due to Malaysia is having Movement Control Order (MCO). For example, the total production of passenger cars had decreased from 533,000 units for year 2019 to 454,000 units for year 2020 which had declined by 15%. The sales of passenger cars also decreased subsequently where it declined by 13% decreased from 550,000 units for year 2019 to 481,000 units for year 2020. Moreover, packaging sector is affected as well. The total exports of plastic products are decreased by 11%, where is decreased from RM15 billion for year 2019 to RM13.3 billion for year 2020. This is because Europe, Korea, Japan, and Australia had weaker demand for plastic products due to the impact by this pandemic. Logistics is another issue that caused the total exports decreased as the Covid-19 lockdown and close-border policy in globe. Therefore, plastic industry in Malaysia is forced to attribute and lower selling prices in order to arise from lower input costs due to lower raw resins costs (Boon, D. L. K., 2020).

Challenges that plastic industry in Malaysia might face in future are managing COVID risk of employees, managing manpower shortage, compliance of foreign workers policies and meeting sustainability requirements. As Covid-19 cases rise

again and MCO is implemented again in Malaysia, the manufacturing sector had been categorized as one of the major sectors of Covid-19 clusters due to it has employs approximately 35% of the total documented foreign workers in Malaysia. Therefore, employers have to take the responsibilities to ensure the full and strict compliance of SOP in order to contain any further spread of Covid-19 from their workplace. Besides, foreign workers who have completed their contract have to return to their home country. Hence, manpower shortage will be one of the major challenges because the approval of intake of new or replacement foreign workers is not accepted by the government. In addition, local workers are usually not willing to work in manufacturing sector and thus lead to the mandatory for all manufacturing sector to comply with the ratio of 20:80 ratio for foreign or local workers by 31st December 2022 become more challenging to achieve. According to Minimum Standards of Housing and Amenities Act 1990 (Act 446), employers are required to provide improved accommodations for foreign workers. However, this will be another challenge for plastic industry in Malaysia because all those issues such as lack of suitable accommodation available, industrial estates is placed nearly to the resident areas and high costs involved in renovating accommodation space are yet to be solve. Last but not least, sustainability is always a challenge for plastic industry. In order to meet the sustainability requirements, manufacture recyclable plastics packaging is one of the current efforts for plastic industry in Malaysia to achieve. Plastic industry in Malaysia is still discovering a new ways or efforts for plastic to become sustainable (Boon, D. L. K., 2020).

2.1.1 Plastic Pollution

Plastic pollution is the accumulation of the synthetic plastics products in the environment. This will create problems for wildlife and their habitats as well as for human populations. This plastic pollution can happen because plastic is a polymeric material which has large molecules that made up by a series of interconnected links. Since Malaysia is one of the largest exporters of plastic products, the plastic pollution also more serious compare with other countries. According to the (Xiang, 2020),

Malaysia is among the worst consumers of plastic packaging in Asia. The **Figure 2.2** shows that Malaysia is the highest in annual capacity of plastic packaging consumption between the six countries which are China, Indonesia, Vietnam, Thailand, Philippines and Malaysia.

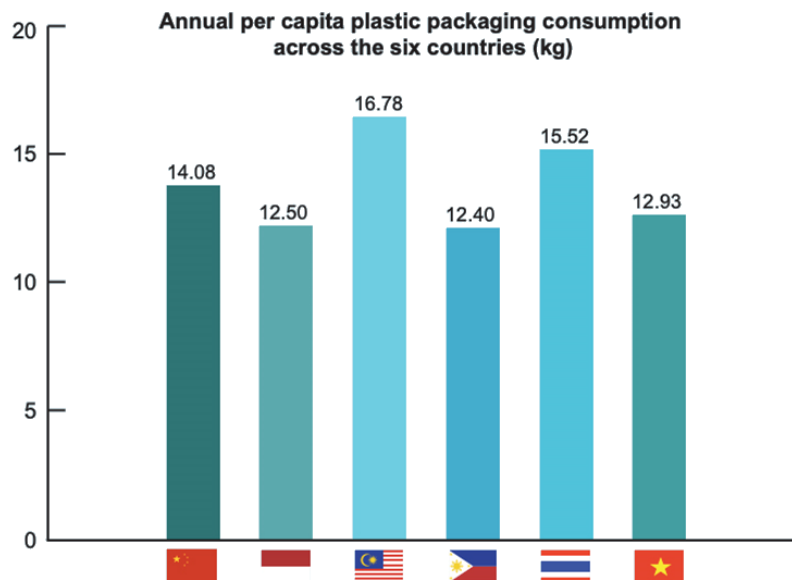


Figure 2.2: Annual Capacity of Plastic Packaging Consumption in Asia (Xiang, 2020).

Figure 2.2 shows that each Malaysian use average 16.78 kg of plastic per year followed by Thailand 15.52 kg per person. Malaysia is the highest in annual capacity of plastic packaging consumption because there are a lot of food delivery plastic packaging and a lot of day-to-day products bought in supermarkets. Besides, Malaysia also is the poorest waste management system country. The **Figure 2.3** shows that the waste disposal rates between the Asia countries. Malaysia has 85% of unsound disposal in the nation which is same as Philippines. This situation is happened because Malaysian households are not compulsory to segregate the rubbish by categories such as paper, plastics and organic waste (Xiang, 2020).

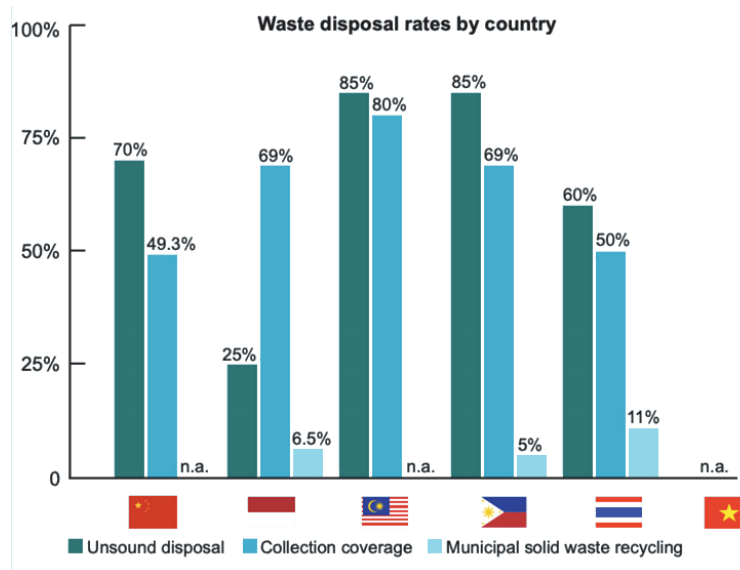


Figure 2.3: Waste Disposal Rates by Countries (Xiang, 2020).

The plastic pollution is affected to environment, wildlife, and human populations. Firstly, the environment will affect simultaneously when the plastic pollution happens. In Malaysia, the municipal solid wastes are either discarded or transported directly to landfill sites. Disposal of plastics is a main problem within the solid waste management cycle. This is because plastics unlike food or paper wastes which are biodegradable. Plastics cannot eliminate in short-term from the environment when just left the plastics degrade in landfills. Plastics need to take about hundreds to thousands year to breakdown into smaller plastics fragments which also known as microplastics. The plastics will accumulate on Earth when the plastics cannot eliminate well and cause decrease of the landfill space (Chen et al., 2021). Furthermore, the environment also will affect when the plastic waste do not degrade well in the landfill. This is because the plastic waste can produce dangerous gas such as methane and this gas can make the landfill site hazardous.

Besides, the human population also will be affected especially health care. Plastic polymers can cause lethargic and concern to public health. Different types of additives of polymers have different affect to the healthier care. Most of the additives that present in the plastics will cause carcinogens and endocrine disruptors. Besides, ingestion, skin contact, and inhalation are the main path of exposure of humans to these additives. For example, bisphenol A is one of the type of additives. This bisphenol A is use as plasticizers which normally appear at polyvinyl chloride or polycarbonate. Mimics oestrogen and ovarian disorder may cause the public health. Furthermore,

phthalates, persistent organic pollutants, dioxins and etc are also the types of the additives. All these additives are appeared at all types of plastics, and it can cause sperm motility, reproductive damage, interferes with testosterone and etc. Therefore, the plastic pollution also can cause a serious problem to the human population (Oa and Oa, 2019).

Last but not least, wildlife also affected during this plastic pollution. Normally, the wildlife is exposed to plastic wastes through ingestion and entanglement. However, ingestion is more frequent compare with entanglement. Most of the animals in the ocean will misunderstanding the plastic waste that dumped into the ocean as food. Hence, the animals will be ingesting them. In addition, entanglement in plastic products such as nets can cause harm, damage and even death in marine animals. According (Oa and Oa, 2019), there are more than 260 different species of vertebrate and invertebrate animals are ingested or entangle by the plastic produced and cause 400000 marine mammal deaths. The plastic waste in the ocean affects the sea turtles because they always confuse the discarded plastic bags as jelly fish. Besides, sea birds also confuse the microplastics as other fishes. Hence, this will damage the digestive system of the bird when they eat the plastic waste.

2.2 Type of Plastic

There are 2 types of plastics which are petroleum-based plastic and biodegradable plastic.

2.2.1 Petroleum-based Plastic

Petroleum-based plastics are artificial organic polymer which obtain from natural gas or oil. Global petroleum-based plastic is produced about 322 million tons in 2015. Compare with year 1950 that produce 1.7 million tons of petroleum-based plastics, year 2015 is more compare with year 1950. The example of petroleum-based plastics

is polyethylene, polyvinyl chloride, polypropylene, polystyrene and etc. The amount of the petroleum-based plastics will increase year by year because petroleum-based plastic can utilize in various applications such as medicinal, industrial area, commercial and etc. When the amount of petroleum-based plastics increase, some of the problems will happen to environment such as plastic pollution, global warming, soil pollution and etc. The petroleum-based plastics maybe can fragment but it cannot break down naturally (Suman et al., 2020).

Petroleum-based plastics have divergent properties such as rigid, elastic, resilient, transparent, and cheap. Almost every household as well as construction equipment contain commodities are fully or partially made up of petroleum-based plastic due to wide range of properties. The huge production and utilization of petroleum-based plastics have become a serious problem to the earth. This is because petroleum-based plastics are affecting the global due to the disposal problems (Barnes et al., 2009).

There are a lot of impact when the petroleum-based plastics are used. Firstly, it will utilize of petroleum and energy resources. Many types of petroleum-based plastics such as ethylene, propylene and styrene are directly extract from the crude oil. When the consumption of the petroleum-based plastics is increasing, significant amount of petroleum and energy are required for synthesis the plastics product. Besides, it also will release heat and greenhouse gas. Heat and carbon dioxide are always release from the plastic industry. When the heat and carbon dioxide are release continuously, the global warming will happen. Last but not least, health hazards also affected because of increasing of petroleum-based plastics. The additives of the plastics are more affect the health hazards (Rasheed, 2011).

2.2.2 Biodegradable Plastic

Biodegradable plastic is a type of plastic that made from by-products. During manufacturing, it usually undergoes a controlled conditions of temperature and humidity environments. It is a kind of plastic that can be decomposed when it exposed to the presence of microorganisms. Most of the biodegradable plastics are also known

as bioplastic which are basically made from plants such as sugarcane or bamboo. In order to let bioplastics to be effectively biodegradable, the compostability of it have to follow to the international standards. European EN 13432 is one of the most recognized biodegradability standards. According to this standard, an effective biodegradable plastic must have a minimum volatile rate of 50% which able to be fragment at least 10% of its initial weight above a 2mm sieve after 12 weeks. After being first composted, it gets at least 90% biodegraded in no more than 6 months and the resulting compost have to perform at least 90% compared to the corresponding reference compost when it comes to toxicity (*Definition of biodegradable, 2020*).

There are two main types of bioplastics which are polylactic acid (PLA) and polyhydroxyalkanoate (PHA). Basically, PLA is made from the sugar in corn starch, cassava or sugarcane and it is biodegradable and carbon neutral. PLA can behave and look alike with polyethylene which normally used in plastic films, packaging and polystyrene which commonly used as plastic cutlery and polypropylene which generally used in auto parts and textiles. For PHA, it is made by microorganisms where is being genetically engineered. The microbes are nitrogen, oxygen and phosphorus which is deprived of nutrients, but it provides high levels of carbon. PHA is produced as carbon reserves which it can store in granules until there are more of the other nutrients need to grow and reproduce. PHA is biodegradable and it will not harm to any living issues. Hence, most of the companies collect the microbe made PHA which has similar chemical structure with traditional plastics. PHA is usually used in medical applications such as slings, bone plates and skin substitutes. In addition, it is can also use for single-used food packaging (Cho, R., 2017).

Bioplastics are more eco-friendly than petroleum-based plastics for a reason. This is because bioplastics produce significantly fewer greenhouse gas emissions than petroleum-based plastics over their lifetime. When the bioplastics decomposed, there is no net increase in carbon dioxide due to the plants that bioplastics are made absorbed the same amount of carbon dioxide as they grew. It had been determined from a 2017 study which stated that corn-based PLA would reduce 25% of greenhouse gas emissions in USA. If the petroleum-based plastics were produced by using renewable energy sources, greenhouse gas emissions could be reduced to 50% or 75%. However, bioplastics are still the most promising for greenhouse gas emissions to be reduced substantially. Bioplastics also have its disadvantages. It is relatively expensive

compared to conventional plastics because of its complex process used to convert the corn or sugarcane into building blocks for PLA. Besides, not all the bioplastics can be recycled. Therefore, it can contaminate the batches of recycled plastics and cause recycling infrastructure if the unrecyclable bioplastics are not discarded properly. If the recycled plastics is contaminated by the unrecyclable bioplastics, the entire lot of plastics are rejected to be recycled and end up in landfill. Hence, it is necessary to separate recycling streams so that bioplastics can be discard properly (Cho, R., 2017).

2.3 Polyvinyl alcohol (PVA)

Polyvinyl alcohol (PVA) is unique polymer which made by multiple units of molecules. When polyvinyl acetate dissolve in methanol, it will treat with catalyst such as sodium hydroxide and produce PVA which undergo hydrolysis reaction. This hydrolysis reaction will remove the acetate group from the polyvinyl acetate molecules without disrupt the long chain structure. The vinyl alcohol structure will repeat and form PVA (The Editors of Encyclopedia Britannica, 2016). The **Figure 2.4** shows that the chemical structure of PVA.

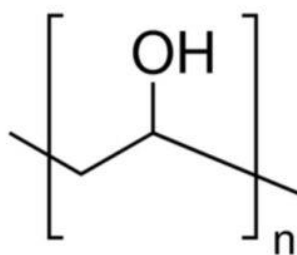


Figure 2.4: Chemical Structure of PVA (Vinit Mehta, 2018).

PVA is a polymer that can be soluble in water but insoluble in partial organic solvents. Besides, it is effective in film forming, emulsifying and it has adhesive quality. PVA can be effective in film forming because it is soluble in water. In addition, it has non-odour, non-toxic, resistant to oil and solvents. PVA is ductile but it is strong, flexible and functions as high oxygen and aroma barrier (Vinit Mehta, 2018).

Normally, PVA can used for industrial products such as coatings, surfactant, film useful for packaging and hygiene products as a biodegradable plastic backing

sheet. Besides, biomedical field also use PVA in different areas. Due to the hydroxyl group and hydrophilic in the PVA, it can compatible with most of the fibre. However, PVA also has some disadvantages. For example, the melting temperature of PVA is higher than its thermal decomposition temperature. Furthermore, viscosity in the melting process is high and cause its difficult in moulding process. Moreover, PVA has a lower breaking elongation. Last but not least, PVA also expensive compare with other. Therefore, PVA need to blend with other natural reinforcement materials such as starch, cellulose, or natural fibre to reduce the cost and increase its properties (Esaheb and Elzatahry, 2014).

2.3.1 Market Demand of PVA

Polyvinyl alcohol (PVA) is slowly gaining popularity and become one of the widely used polymer in the world for the application which relate to food packaging, construction, textile, cosmetics, and paper. This is because the properties of PVA are biodegradable, water soluble, non-toxic, high tensile strength and etc. The global market size of PVA was estimated USD714.5 million in 2016 and anticipated to expand with compound annual growth rate (CAGR) of 6.1% during the forecast period of year 2014 to 2025 (www.grandviewresearch.com, n.d.).

Due to COVID-19 in year 2020, there was some negative impact to the market of PVA especially paper manufacturing sector. The demand of drop from various paper consuming segment such as newspaper or magazine led to market demand of PVA in paper manufacturing sector also decreased. However, the usage of food packaging are increased and thus, the demand of PVA also increased significantly. From the **Figure 2.5**, it showed that the market demand of PVA is increased from year 2014 to 2025 based on the CAGR of 6.1% (www.grandviewresearch.com, n.d.).

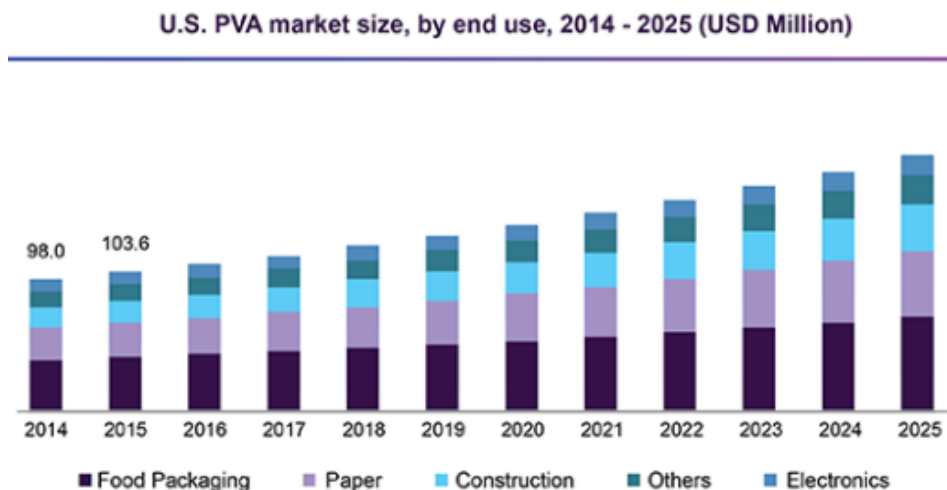


Figure 2.5: Market Demand of PVA from Year 2014 to 2025

(www.grandviewresearch.com, n.d.).

The demand of PVA will increase year by year because dominated by the food packaging. The food packaging industry is the largest consumer of PVA. Majority, PVA is used as binding and coating agent in the food packaging industry. PVA is used as a binding and coating agent to avoid the active food ingredient from being exposed to oxygen, moisture, or other environmental components. Besides, it can also be used in the food packaging industry because it is odourless and tasteless. Due to the properties of PVA, the global food packaging market is projected to increase from USD 305 billion in 2019 and is estimated to reach about USD 406 billion in 2024, with a CAGR of 5.8% (Mordor Intelligence, 2021).

2.4 Agricultural Waste

Agricultural waste is the waste produced as a result of various agricultural operations. This agricultural waste includes other wastes from farms and poultry houses, harvest waste, fertilizer runoff from fields, and etc. In Malaysia, the waste management system was not important in the early 1970s. The amount of waste was increasing every year. Landfill is an essential necessity for waste management, and this has caused the amount of landfill to decrease year by year. In Malaysia, there are about more than 30,000 tonnes of municipal solid waste generated, and 95% of municipal solid waste are

disposes directly into landfill. Hence, the need for sustainable landfills is very crucial to avoid undesirable impacts to human health and environment (Agamuthu and Fauziah, 2010).

The traditional waste management system by local government is not efficient and unsustainable. This is because Malaysia waste generation per capital is increased from 0.5kg/day in 1980s to more than 1.3kg/day of waste in 2009. This cause annual waste generation in Malaysia had reached 11 million tonnes and the main waste is organic waste which is 55% of the total waste (Agamuthu and Fauziah, 2010). The **Figure 2.6** shows that the typical municipal solid waste composition in Malaysia. This organic waste mostly come from food processing industries such as juice, chips, meat and fruit industries (Sadh, Duhan and Duhan, 2018). The organic waste also known as agricultural waste.

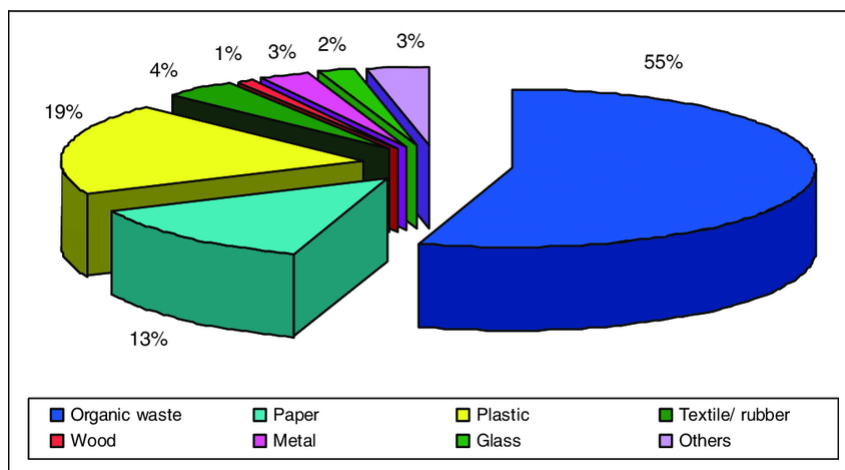


Figure 2.6: Typical Municipal Solid Waste Composition in Malaysia (Sadh, Duhan and Duhan, 2018).

These agricultural wastes can be utilized for different energy sources. As the population in Malaysia increase simultaneously, the requirement of food and uses also will increase. Different compositions of fruit industrial wastes contain different compositions of cellulose, hemicellulose, starch, ash and etc. These compositions have potential to produce useful products such as biogas, bioplastics, and other commercial goods. The agricultural wastes that produce from fruit industries contains high value of BOD, COD, and other suspended solids. When these wastes are not treated well, it will affect the environment as well as human and animal health. Meanwhile, when the

wastes are treated correctly, these wastes can produce valuable products and reduce the production cost (Sadh, Duhan and Duhan, 2018).

2.4.1 Banana Peel Waste

Banana is grown originally from Malaysia and now is almost all over the country in the world especially in tropical and subtropical countries. This is because the tropical and subtropical countries have been sustainably cultivated. Hence, banana is one of the most important crops in the world. There are 106 million tons of bananas were produced in 2013 and 57% of the bananas were produced in Asia while America is produced 26% (ScienceDaily, 2016). India is the largest banana producing country in the world which can produce more than 25% of the banana, followed by China (Padam et al., 2012).

Generally, peels are commonly to be the waste part of various fruits. All these wastes have not received much attention with a view to being used or recycle rather than discharged. The peels are rather than discharged because of their unknown benefit of commercial application. The banana peel is the main by-product of the banana processing industry. According to (ScienceDaily, 2016), it stated that the ratio of banana waste and product is 2:1. The **Figure 2.7** shows the banana peel waste (BPW). This BPW consider as an agricultural waste. This by-product can cause an environmental problem because it contains large quantities of nitrogen, phosphorus and high water content (R. González-Montelongo et al., 2010). A slightly better application of banana waste was utilized as an animal feed to minimize the cost of production. The con is this application required additional processing because BP is high water content which can reduce the nutritional density. Normally, low cost agriculture wastes have poor essential nutrient but high in fiber content at the same time.



Figure 2.7: BPW.

BP is a renewable resource, and this resource can be turned into raw materials or products that have potential capacity of being recyclable and easily biodegradable. When this BP turn into raw materials or products, it will have positive environmental acceptability. This renewable resource can replace the non-renewable resources especially petroleum and gas products. Starch, pectin, and cellulose are used as thickening agent or stabilizers. BP can be processed into starches and this banana starches is low in amylase content. These starches have high resistance to amylase attack. Besides, the banana starches also have low solubility in water, low retrogradation, low swelling properties and etc. Moreover, pectin is a structural heteropolysaccharide which can classify under soluble dietary fibre. The pectin is normally produced from extraction of fruits such as orange peels, apple peels, carrots and etc. The pectin also can be produced in banana peels through acid extraction and precipitation by using alcohols or ammonium salts. The quality of pectin is isolated from various fruits wastes, revealed that the pectin's methoxyl composition and gelling quality of banana is slightly lower that pectin that isolated from orange peels (ScienceDaily, 2016).

2.4.2 Orange Peel Waste

Orange is the most abundant fruit crop in the world, and it is consumed in a large quantity in global. Vitamin A, B, C, and minerals such as calcium, potassium, and phosphorous are the nutrients that can find in orange. However, orange peel waste

(OPW) is usually being underutilized and consider as biowaste residue due to extraction of orange juice can only accounted for 50% of its original fruit mass. The major remaining dry waste are the pulp, seeds, peels and membrane residue after the extraction of orange juice. The OPW have valuable polysaccharides such as pectin, cellulose and hemicellulose whereas the pulps can be monosaccharides or disaccharides which in the form of soluble sugars such as glucose, fructose and sucrose (Nur Farhana Fadzil, S. A. O., 2021).

OPW also contains large amount of moisture which is around 80% to 90% of water content and consists high level of sugars, polysaccharides, essential oils and polyphenols. Nowadays, OPW had discovered to become a necessary raw material for sustainable products because the chemicals that confined in OPW are able to be used as a new building block in the products ranging from plastics to paracetamol. Therefore, it had helped by making a breakthrough on the reliance of crude oil. OPW also have good thermal and chemical properties. For example, when OPW is contact with other material surface, some of the heat will be generated due to friction. OPW act as self-lubricant due to the presence of some oil in its outer part and thus it does not need to supply any lubricant (Marsi, N. *et al.*, 2019). The **Figure 2.8** shows orange peel waste.



Figure 2.8: OPW.

However, it also come with some disadvantages. For example, since most of the industry have large amount of OPW during extraction of orange juice but they cannot ensure their total amount of orange peel waste can be fully used. The remaining OPW is usually being disposal through landfilling. If the waste did not disposal properly, it might cause some impacts on the environment. Moreover, high water content and organic matter of OPW can also cause environmental problems if it is not being treated well due to the low pH level (Marsi, N. *et al.*, 2019).

There is other useful utilization of OPW that commonly be done such as cattle feed and composting. Cattle feeds are able to satisfy with waste like OPW since it does not need to compete with other crops for human consumption. OPW is used to fertilize others crop through composting process. This can help to increase the organic load of soils and improve the water retention capacity which is full of nutrients. Other than that, it also helps to prevent plant infection by pathogens like fungi. Actions such as incineration of OPW and dump storage of OPW is not recommended. Incineration of OPW able to obtain thermal energy and power and reduce the waste volume but it also will generate greenhouse effect gases to the environment. Thus, this action is seldom to use unless it is necessary to do so. Dumpling OPW into a dump storage is commonly be used despite it might cause health and environment issues. OPW is vulnerable to fermentation due to it is rich in sugar, salt, protein and high water content. Thus, it is not encouraged to disposal by dump OPW into dump storage so that health and environment can be protected. Due to OPW is rich in organic compounds and generate issues during disposal, it had shown a great potential for valorisation within the biorefinery strategy by involve the application of pre-treatments (de la Torre, I. *et al.*, 2019).

2.4.3 Jackfruit Waste

Jackfruit waste (JW) can be categorized into two type of waste which are edible waste and non-edible waste. Example of edible waste are jackfruit seed whereas for non-edible waste are jackfruit peel and central core or axis of jackfruit. If JW is disposal unsystematically, it will cause a serious problem to the environment. However, a proper utilization of jackfruit waste can increase the economic value, reduce the cost of disposal and reduce the environmental impacts (Haque, M. A., 2019).

Jackfruit peel (JP) is the outer layer of the fruit which known as rind or skin. It is rich in cellulose, pectin, protein and starch. It can be contributed to the economic development through utilization of JP for production of pectin. However, the extraction of pectin from JP is low quality due to its poor solubility and high ash content when compared to commercial pectin. Hence, more advanced techniques are

implied nowadays which include ultrasound assisted extraction and ultrasonic microwave assisted extraction so that higher pectin yield can be produced. Besides, JP is being tested for suitability to be used as an efficient raw precursor for production of activated carbon. The other utilization of JP is biofuel and bioactive compounds extraction which can be used as an alternative for non-renewable resources such as fossil fuel (Ranasinghe, R. A. S. N., Maduwanthi, S. D. T. and Marapana, R. A. U. J., 2019). The **Figure 2.9** shows the JP.



Figure 2.9: JP.

Jackfruit contains 10% to 15% of jackfruit seeds where these seeds are very rich in starch, protein and minerals. Jackfruit seeds also known as *Artocarpus heterophyllus*. Jackfruit seeds had become the potential alternative source of starch because it contains higher level of starch due to the presence of cotyledons (Mohammad Kahar Ab Wahab, M. Lingeswarren, Amirah Hulwani Mohd Zain, Hafani Ismail, 2019). It is discovered that the amylose content in jackfruit seed starch is around 24% to 32% which is similar to the potato starch. Jackfruit seed starch is cheap, and it is available abundantly from multiple crops in every year. The recovery of jackfruit seed starch is about 77% which make it being used as a potent source of starch in food and pharmaceutical industries. The conversion of jackfruit seeds into flour can enhanced its utilization for extraction. It is also being developed in the production of polymer blends and replacing other food-based starch that available on the market. Jackfruit seed also contain significant amount of non-reducing sugar which is suitable to be utilized as prebiotics. It also has been tested for its dominant application as raw material for production of ethanol which can considered as a renewable source of energy. Besides, it also acts as source of protein in food industry due to its high protein content (Ranasinghe, R. A. S. N., Maduwanthi, S. D. T. and Marapana, R. A. U. J., 2019).

Basically, starch and synthetic plastics are conflicting, and they do not mix easily. This is because it will become a heterogeneous product. Actually, it is unsuitable for most conventional applications due to properties of starch. However, it is reported that the gelatinization temperature of jackfruit seed starch is higher than the other sources of starch. In order to make it compatible, it has to be modified chemically or physically so that its attributes can be enhanced positively and also minimize its defects (Mohammad Kahar Ab Wahab, M. Lingeswarren, Amirah Hulwani Mohd Zain, Hafani Ismail, 2019).

2.5 Plasticizer

Plasticizer is a non-volatile, high boiling, low molecular weight organic substances and normally it presents in liquids form. When plasticizer mix with plastic or elastomer, the plasticizer can help to improve the properties of the polymer such as increase the flexibility, extensibility and processability by modifying the mechanical properties and make the films more ductile (SpecialChem, 2015). Besides, plasticizer also can increase the flow and thermoplasticity of a polymer by decreasing the viscosity of the polymer, glass transition temperature, the melting temperature and the elastic modulus of the product. The function of the plasticizer is to increase the elasticity of the polymer without changing the fundamental chemical character of the plasticized material.

Normally, plasticizer is produced by a reaction which an alcohol reacts with acid such as adipic acid or phthalic anhydride. The kind of plasticizer is determined by the types of esters that can produced. Hence, the types of alcohol and acid that choose is important (Vera Koester, 2015). There are several properties of plasticizer. Firstly, plasticizer is non-volatile solvents. The plasticizer has high boiling point and low volatility. These properties are important because the plasticizer will evaporate from a plastic or film and then revert to original brittle condition. Furthermore, plasticizer has high boiling point which can reach until 300°C. The plasticizer must chemically inert, fast to light, resistance to moisture, non-toxic and non-fuming. These properties are very important because the plasticizer cannot alter the chemical character of the polymer. Besides, the plastic material should not contain any smell or taste because

the plasticizer also needs to use in the packing food or beverages. Last but not least, the plasticizer should possess basic characteristics such as impart flexibility, compatible with polymer, insoluble and stable in water.

Plastics with plasticizers is almost used for every industry which included medical industry, automotive industry, telecommunications and etc. In the medical industry, they will create the flexible devices and bags. Besides, plasticizer can used in automotive industry to mould the flexible hoses. Plasticizer can also be used in clothing design to make shoe soles so that the shoe soles is more flexible and comfortable. Furthermore, plasticizer can make the telecommunication more durable, low-friction, flexible casing in the underground wires and cables (Advanced Plastiform, 2020). Plasticizer is safe to use in every industry because plasticizer does not affect the environment too much.

2.5.1 Glycerol

Glycerol is one of the types of plasticizers. Glycerol normally used as plasticizer for starch because it is compatible with amylose. Glycerol can promote the mechanical properties better by interfering with amylose packing, thereby decreases the intermolecular forces between the starch molecules (Dianursanti, Gozan and Noviasari, 2018). When the composition of glycerol increase, it will cause the film thickness, moisture content and solubility in water also increase. Meanwhile, the density and water absorption were reduced. In addition, glycerol as plasticizer will cause the elongation at break of film increase. This is because of the reduction of intermolecular forces and increase polymer chain mobility (Tarique, Sapuan and Khalina, 2021). Normally, glycerol is used as plasticizer to produce thermoplastics starch (TPS).

There are several advantages of glycerol as a plasticizer. Firstly, glycerol is non-toxic substance. This is because it can used as medicine which can weight loss,

improving exercise performance, reduce pressure inside the eye and etc (RxList, 2018). It always available in large quantities and more cost effective. Furthermore, the boiling point of the glycerol also is an advantage because it has higher boiling point which is 290°C (PubChem, 2004). Last but not least, glycerol has low cost because it is the by-product of the biodiesel production, and it has potential to improve the economics of biodiesel and bioplastic industries (Yang, Hanna and Sun, 2012).

2.5.2 Lactic Acid

Lactic acid is a bio-fermenting compound which have excellent biomass reproducibility. Due to left-handed features and able to be metabolized by human body without any toxic side effect, lactic acid has shown its good biocompatibility properties (Liu, T. *et al.*, 2017). Lactic acid can be generated as Poly (lactic acid) which also known as PLA. PLA is produced from fermentation of renewable sugar supply. For example, starch and polysaccharides which produce by PLA (Mekonnen, T. *et al.*, 2013). It has relatively low production cost and possesses several physical characteristics which is similar to conventional thermoplastic such as high strength, thermoplastic fabricability, biocompatibility, good aroma barrier, good crease retention and grease/oil resistance (Ljungberg, N. and Wesslén, B., 2005).

However, PLA has its own disadvantages. It is found that polymer with lower molecular weight has higher crystallization rate due to chain mobility increased. When lactic acid undergoes condensation polymerization process, a polymer with low molecular weight is produced. This kind of polymer is brittle and glassy. Since PLA is generated by lactic acid, it is known as a low molecular weight polymer. This is because it is fragile with low impact resistance due to huge amount of crystallinity contained in it. Hence, it causes PLA has properties of high brittleness and low thermal stability (Chieng, B. W. *et al.*, 2016).

2.5.3 Sorbitol

Sorbitol is a type of TPS. TPS is obtained through direct modification of starch such as an addition of sorbitol as plasticizer. TPS can be obtained by destroying the crystalline structure of starch. Since starch can deform under flow leading to finer dispersions, the addition of starch in its thermoplastic state is more promising (Li, H. and Huneault, M. A., 2011). Starch is also act as the feedstock of sorbitol where it goes through aminolysis reaction and hydrogenation process (Furtwengler, P. *et al.*, 2017).

Besides, the presence of sorbitol in starch able to decrease the glass transition temperature of TPS which it will enhance the properties of TPS such as increase its thermal stability. TPS is able to improve its water resistance properties with the use of sorbitol. It is due to the sorbitol plasticized TPS has higher decomposition temperature and lead to reduction of water absorption due to stronger starch-sorbitol interaction. The benefit of using sorbitol as plasticizer is it has lower volatility during blend preparation compared to other plasticizers like glycerol. This is because sorbitol has higher melting point than glycerol which is 95°C for sorbitol and 18°C for glycerol. However, it also has its own disadvantages. The tendency of migration of part surface and recrystallization had limited the use of sorbitol as plasticizer for starch. Hence, it had cause TPS become brittle (Li, H. and Huneault, M. A., 2011).

2.6 Combination of PVA with Natural Fibre

Due to the limitation mechanical properties of PVA and the high cost of PVA, the natural fibre can add in to improve their mechanical properties.

2.6.1 Natural Fibre Reinforced PVA Based Composite

The combination of PVA with natural fibres is a well-developed composite where it can form eco-sustainable composites. Hence it able to achieve the sustainable goals. However, there are four factors that can affect the strength of polymer composites

which are the properties of matrix, the compatibility of reinforcement-matrix, the dispersion of reinforcement in matrix and the properties of reinforcement. In PVA/natural fibres composites, the presence of -OH groups that consists in natural fibres and the hydrophilic nature of natural fibres are compatible with PVA. This had led to a good interaction between natural fibres and PVA. Based on that, combination of PVA and natural fibres can enhance the mechanical properties of polymer composites such as showed good fibre/matrix bonding, high tensile and exhibited Young's modulus with maximum fibre content (Tan, B. *et al.*, 2015). The **Table 2.1** shows that the example of the natural fibres and their mechanical properties.

Table 2.1: Mechanical Properties of Several Natural Fibres (Tan, B. *et al.*, 2015).

Natural fibres	Density (g/cm ³)	Young's modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)
Flax	1.54	27.5-85	345-2000	1-4
Ramie	1.5-1.56	27-128	400-1000	1.2-3.8
Hemp	1.47	17-70	368-800	1.6
Jute	1.44	10-30	393-773	1.5-1.8
Sisal	1.45-1.5	9-22	350-700	2-7
Coconut	1.15	4-6	131-175	15-40
Cotton	1.5-1.6	5.5-12.6	287-597	7-8
Kenaf	1.2	14-53	240-930	1.6
Bamboo	0.6-1.1	11-17	140-230	-

Solution casting method, extrusion and injection moulding are the common processing methods to produce natural fibre-based composites. However, natural fibres have low thermal stability, and this had become its disadvantage during processing. Hence, natural fibres-based composites are preferable to be process at low temperature which is usually limited to 200°C and shorter processing time. If it processes at high temperature, the degradation of natural fibres can occur. Moreover, the presence of plasticizer able to achieve low temperature when processing natural fibre-based composites. Besides, it can also avoid the decomposition of fibres. Since PVA/natural fibres composites are eco-friendly products and good mechanical properties therefore its application is widely used in various area such as application for food packaging material and mulch films, application in agriculture area, application in medical field and etc (Tan, B. *et al.*, 2015).

2.6.2 PVA incorporated with Various Type of Cellulose

PVA incorporated with various type of cellulose due to the properties of the cellulose such as toughness, flexibility, easy processing, recyclability and eco-friendly. There are two main types of cellulose such as microcellulose and nanocellulose (Tan, B. *et al.*, 2015).

Microcellulose is made up of very short fibres and microcellulose is introduced to overcome the limitation of PVA when they are combining with each other. There are 2 types of microcellulose which are microfibrillated cellulose (MFC) and microcrystalline cellulose (MCC). MFC is an interconnected web-like structure of tiny fibrils and microfibril bundles. When the high volume cellulose expand in new form, the surface area need to increase in order to produce the composites. PVA/MFC composites is form when the blending of MFC suspension with PVA. The MFC inhibited the crystallization of PVA. MFC will prohibit the free movement of polymer chain and ability to lower their crystallinity. PVA/MFC has a strong bonding which can contribute to the excellent mechanical properties and high thermal stability of the composites. Generally, PVA/MFC can replace the traditional plastic materials in many applications such as racket frames, circuit boards, automobiles and more (Tan, B. *et al.*, 2015).

MCC is produced by using hydrochloric acid and hydrolysis reaction. They will dissolve the amorphous region of cellulose. Hence, cellulose microcrystals are separated. The tensile strength and modulus will increase when the content of MCC is increase up to 9%. When the content of MCC is increase above 9%, the tensile strength and modulus will decrease due to the aggregation in the composites. PVA/MCC indicate no cytotoxicity and thus, it is normally be used in biomedical field such as wound dressing. Moreover, MCC can also enhanced the crystallinity of the PVA. The crystallization of PVA was confined and its melting temperature was decreased when the MCC is added into PVA. This is beneficial for melting process of PVA (Tan, B. *et al.*, 2015).

Nanocellulose can produce through treatments on macro and micro size of cellulose. There are 3 types of nanocellulose which are cellulose nanocrystals (CNC), cellulose nanofibrils (CNF) and bacterial cellulose (BC). All these types of nanocelluloses are produce in different method. Destruction method is applied to obtained CNC and CNF whereas BC is synthesized from bacteria. Normally, PVA/nanocellulose used solution casting method to prepare it. The advantages of nanocellulose are biodegradability, having excellent mechanical properties and light weight. PVA/CNC composites are considered as improved mechanical properties and barrier properties (Tan, B. *et al.*, 2015).

CNF can be produced from wood fibres, cotton and agriculture crops. CNF can improve the tensile strength and Young's modulus with values 2.4 and 2.8 times larger compare with neat PVA. PVA/CNF exhibit good thermal stability and excellent transparency with a visible light of transmittance of 73.7%. Generally, PVA/CNF possess good elastic properties, excellent transparency, and good absorption of UV rays (Yuwarech, Wootthikanokkhan and Tanpichai, 2015).

BC can be produced by fermentation of sugar and the diameter of BC in the range between 25 to 200 nm (Yuwarech, Wootthikanokkhan and Tanpichai, 2015). PVA/BC shows better mechanical and optical properties because the homogenization and effectiveness in the intermixing of components. When the BC is added to the glyoxal which is cross-linked together, it will form matrix of the composites. The addition of cross-linker may resist the loss of PVA during washing and purification processes. PVA/BC can also show the dimensional properties as well as high moisture and thermal stability. Moreover, Young's modulus and tensile strength also will increase when BC reinforced with PVA. The amount of the BC will affect the Young's modulus and tensile strength of the composites. When the amount of BC increase, the Young's modulus and tensile strength of the composites will also increase (Tan, B. *et al.*, 2015).

2.7 Synthesis of Polyvinyl Alcohol Film

Solution casting method and injection moulding process are the method to synthesis of polyvinyl alcohol films.

2.7.1 Solution Casting Method

Solution casting is an easy and versatile method to produce PVA thin film in laboratory scale. In the solution casting of polymer nanocomposites, the polymer and all the necessary material will dissolve in the common solvent to obtain a homogeneous solution. After that, cast the homogeneous solution onto a flat glass plate and let it evaporate. Once the evaporation of solvent is complete, peel off the dried membrane from the flat glass plate (Roy and Singha, 2017). The **Figure 2.10** shows that the general produce for the solution casting method.

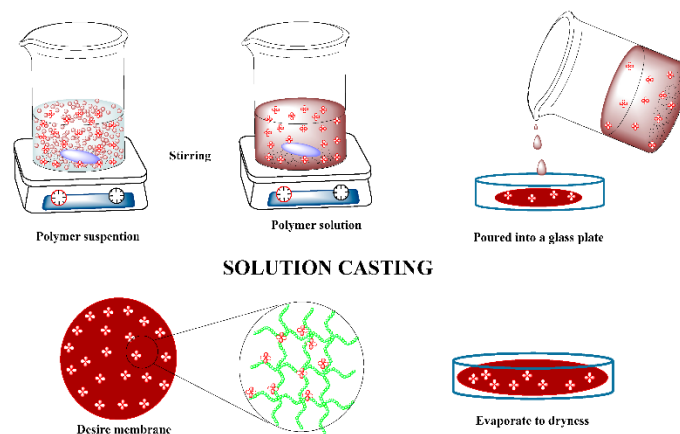


Figure 2.10: General Procedure for Solution Casting (Roy and Singha, 2017).

There are several advantages when using casting solution method compare with traditional extrusion methods. Firstly, casting solution can process at low temperature which valuable for thermally activated films. Besides, it also ability to produce high temperature resistant films from non-thermoplastic but the disadvantage is it is soluble in raw materials. The solution casting method is easy incorporate of additives and fillers. Moreover, it can single pass manufacturing of multilayer films which ability to cast a free film. Last but not least, casting solution can use in wider

range of material choices with casting from aqueous or solvent based solutions (Maria Koomen, 2015).

The advantages of the film that made by solution casting method is it is greater film thickness uniformity. Besides, the thickness of film can form from 150 microns to 12 microns or more. The films that made by solution casting are gel and pinhole free and the film is excellent flatness and dimensional stability. The film is isotropic orientation which is not stretched during manufacture. In addition, film also absence of typical extrusion process lubricants (Maria Koomen, 2015).

2.7.2 Injection Moulding

Injection moulding is the most common used to manufacture fabrication of plastic parts. The injection moulding process requires an injection moulding machine, raw plastic material and mould to produce the plastic. This process is used a reciprocating screw mechanism for melting the plastic and inject it into a mould. After that, the rotation of the screw forces the granules against the heated walls of the cylinder and cause them to melt. When the sufficient plastic materials are melted at the mould end of the screw, the screw will stops and injects the melted plastic into closed mould cavities. The mould is opened and the exceed part is reject from the mould with air (Dr Dmitri Kopeliovich, 2014). The **Figure 2.11** shows that the principle scheme of injection moulding.

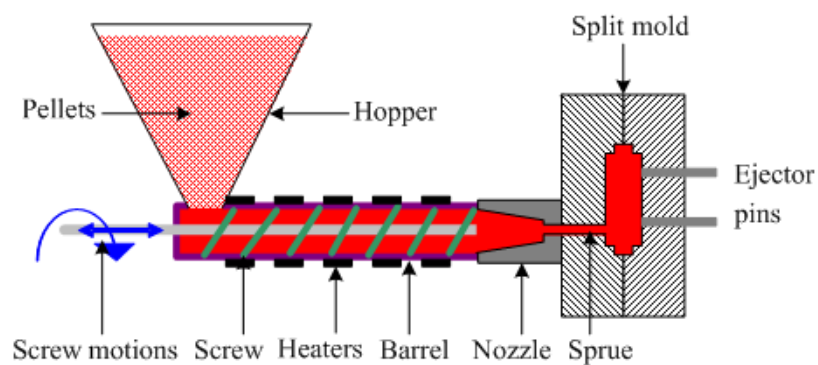


Figure 2.11: Principle Scheme of Injection Moulding (Dr Dmitri Kopeliovich, 2014).

Normally, thermoplastics is using the injection moulding but elastomers and thermosets are extruder. The common thermoplastics that use injection moulding are polypropylene, polycarbonate, acrylonitrile-butadiene-styrene and nylon 6. This process is used to produce the large size and complexity plastics such as pipe, automobile bumpers, battery casings, television cabinet and more (Dr Dmitri Kopeliovich, 2014).

There are a lot of advantages of this injection moulding process. Firstly, injection moulding process has high quality part. High quality parts can be produced at high production rate. Besides, it is low labour costs which it can automated process by using machines and robotics. The product consistency also is an advantages of injection moulding. This process is a repeatable process in the other words the second part is going to be identical to the first product. This is the advantages when try to produce high tolerances and part reliability in high volumes. However, this process also got disadvantages such as small runs of parts can be costly. Due to the complexity of tooling and necessity to rid the machine of all previous material before the next product can be made. Moreover, the setup time is quite lengthy (Guest, 2019).

2.8 Mechanical Properties of PVA Blend Film

Tensile strength, elongation at break and toughness are the mechanical properties that can test the PVA blend film when the force is applied.

2.8.1 Tensile Strength

Tensile strength is an ability of PVA blend film to withstand maximum amount of tensile stress when it being to pull or stretched without failure. In the other word, tensile strength is the resistance of film to break under tension which is a function of stress and strain as well as cross-sectional of the film. Tensile stress can calculate by

using *equation 2.1* which force taken to break film per cross-sectional area (Omnexus, 2020).

$$\text{Tensile strength, } \sigma = \frac{\text{force that applied in the film, } F}{\text{cross-sectional area of film, } A} \quad (\text{Equation 2.1})$$

There are three types of tensile strength which are yield strength, ultimate strength and breaking strength. Yield strength is the stress of the film can withstand without permanent deformation. Besides, ultimate strength is the maximum stress which the film can withstand without failure. Meanwhile, breaking strength is the stress coordinate on the stress-strain curve at the point of rupture (Corrosionpedia, 2011). The **Figure 2.12** shows the typical stress-strain curve.

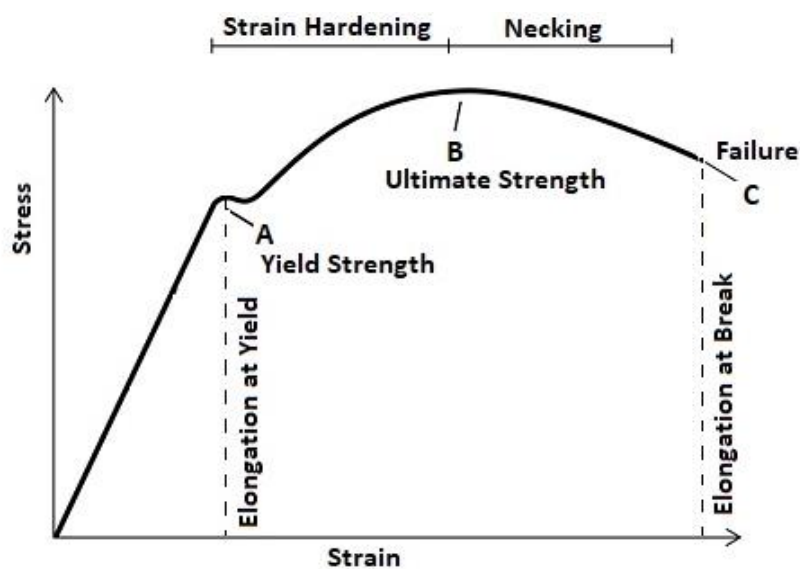


Figure 2.12: Typical Stress-strain Curve (Omnexus, 2020).

2.8.2 Elongation at Break

Elongation at break also known as fracture strain or tensile elongation at break. Elongation at break is measure the ductility of the blending film. This measurement shows how much of the film can be stretched. This indicates the ability of the film to undergo significant deformation before failure. When the film has higher percentage

of elongation at break, it shows that the film has higher ductility. Higher ductility of the film will be more likely to deform and not easy to breakdown. Whereas lower ductility of the film will fracture before deforming when the tensile load is applied (Polyglobal, 2018). Actually, elongation at break is the ratio between increased length and initial length after breakage of the test specimen at control temperature. The elongation is calculated as the relative increase in length. **Equation 2.2** shows that the formula to calculate the elongation (Omnexus, 2019).

$$\text{Elongation, } \epsilon = \frac{\text{Final length of specimen, } \Delta L}{\text{Initial length of specimen, } L} \times 100\% \quad (\text{Equation 2.2})$$

Generally, synthetic fibres show better mechanical and physical properties compare with the natural fibre. Whereas elongation at break and specific modulus are better in natural fibre compare with synthetic fibre. This is because it considers as an important factor in polymer engineering composites (S.R. Djafari Petroudy, 2017).

2.8.3 Young's Modulus

Young's modulus is also known as tensile modulus, elastic modulus or modulus of elasticity. Young's modulus means that the ratio of the stress that applied on the material along the longitudinal axis of the specimen tested and deformation which measure on the same axis. When the tensile force is applied to the PVA film, it will extend and its behaviour can be obtained by using stress-strain curve in the elastic deformation region (The Editors of Encyclopedia Britannica, 2019). In the other word, Young's modulus is used to measure the stiffness of the PVA film by using the concept of stress and strain. Young's modulus is equal to the longitudinal stress divided by the strain. The stiffness of the film can compare with Young's modulus by using measurement of stress and strain. Young's modulus can be calculated by using formula **equation 2.3** (Omnexus, 2012).

$$\text{Young's Modulus, } E = \frac{\text{stress, } \sigma}{\text{strain, } \epsilon} \quad (\text{Equation 2.3})$$

CHAPTER 3

METHODOLOGY

3.1 Process Flow Chart

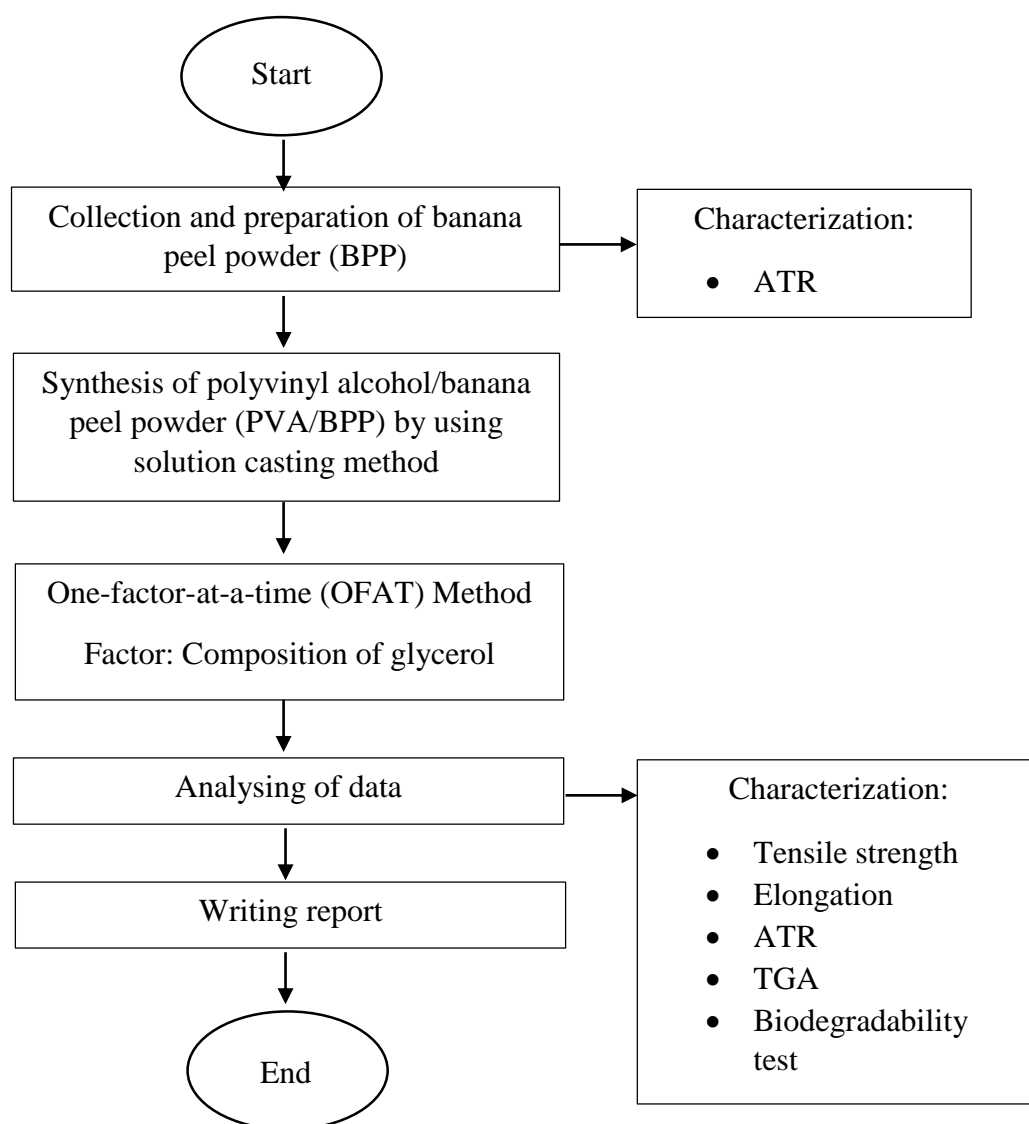


Figure 3.1: Overall Process Flow Chart.

3.2 List of Materials and Chemicals

The **Table 3.1** was listed all the materials and chemicals during this study.

Table 3.1: Materials and Chemical List.

Materials and Chemicals	Description
Banana peel powder (BPP)	It used as a filler during the film production.
Polyvinyl alcohol (PVA)	It used as the main polymer during the film production.
Glycerol	It used as plasticizer during the film production.

3.3 List of Equipment and Apparatus

The list of equipment and apparatus were listed at the **Table 3.2**.

Table 3.2: Equipment and Apparatus List.

Equipment and Apparatus	Description
Beaker	It used to place the mixture or chemicals.
Glass plate	It used to cast the PVA/BPP during film production.
Hot plate stirrer	It used to mix and heat the PVA/BPP solution.
Measuring cylinder	It used to measure the amount of chemicals.
Weight balance	It used to measure the amount of the BPP and glycerol.
Magnetic bar	It used to stir the mixture.
Blender	It used to blend the BP.
Tray	It used to place the BPP for drying purpose.
Water bath	It used to heat PVA/BPP solution.
Drying oven	It used to dry the banana peel before film production.

Equipment and Apparatus	Description
Dumbbell cutter	It used to cut the PVA/BPP blend film into dumbbell for tensile test.
Digital micrometer	It used to measure the thickness of PVA/BPP blend film.
Tensile tester	It used to determine the tensile strength of PVA/BPP blend film.
Attenuated total reflectance spectroscopy (ATR)	It used to determine the functional group of BPP and PVA/BPP blend film.
Thermogravimetric analysis (TGA)	It used to determine thermal properties of PVA/BPP blend film.

3.4 Collection and Preparation of Raw Material

Banana peel powder (BPP), polyvinyl alcohol (PVA) and glycerol are the main raw materials that used in this study. The banana peel (BP) was collected from several fruit stall. The collected BP was dried in the drying oven at temperature of 60°C for about 24 hours to remove the moisture that contain inside the BP. When the BP was dried, blender was used to blend the BP into powder. After that, kept it in a dry place for further usage. Meanwhile, PVA and glycerol with the purity of 99.5% were get from Sigma Aldrich.

3.5 Synthesis of PVA/BPP Blend Film by Using Solution Casting Method

Firstly, 80 wt% of the PVA powder was added into 100 ml of distilled water in a 250 ml beaker. After that, the solution was stirred for 30 minutes with a constant speed on a hot plate stirrer by using a magnetic stirrer bar until PVA was dissolved completely. At the same time, the solution must constant the temperature which is 90°C. Meanwhile, 20 wt% of the BPP was added into 25 ml of distilled water in a 100 ml beaker and stirred it for 30 minutes at 35°C. Next, 10 wt% of the glycerol was mixed

and then stirred it continuously in beaker. The solution was heated on hot plate for 15 minutes at 90°C. The PVA solution and BPP solution were mixed together and then the solution was put inside the water bath until all the bubbles and foams were removed. The PVA/BPP solution was poured on a cleaned glass plate and dried for 24 hours at room temperature. The blended film was further dried in oven 30 minutes at the temperature for 30 °C. After that, the blended film was stored at room temperature for further analysis (Tarique, Sapuan and Khalina, 2021). These steps were repeated by using different composition of the glycerol. The **Table 3.3** shows the preparation of PVA/BPP blend films according to the formulation.

Table 3.3: Formulation of Prepare PVA/BPP Blend Films.

Blend	PVA (% w/v)	BPP (% w/v)	Glycerol (ml)
1	80	20	0
2	80	20	0.5
3	80	20	1.0
4	80	20	1.5
5	80	20	2.0

3.6 One-factor-at-a-time (OFAT) Method

OFAT method is defined to determine the optimum condition of second variable by fixing one input variable. The important parameter in this study is the composition of glycerol. The weightage of PVA and BPP will keep constant which are 80 wt% and 20 wt%. The only factor will change is the glycerol which change to 0ml, 1.0ml, 1.5ml and 2.0ml. Three replicates were tested, and the standard values were recorded.

3.7 Analysis of Data

Attenuated total reflectance spectroscopy (ATR), thermogravimetric analysis (TGA) and biodegradability test were used to analyse the composition of PVA/BPP blend film. Besides, the tensile tester was used to analyse the mechanical properties of PVA/BPP blend film. Furthermore, ATR also used to analyse the composition of BPP.

3.7.1 Attenuated Total Reflectance Spectroscopy (ATR)

Attenuated total reflectance spectroscopy (ATR) is a technique used to detect different functional group which existed in the BPP and PVA/BPP blend film. The Perkin Elmer Spectrum Two was used in this study and **Figure 3.2** was showed this mode. Isopropanol alcohol was used to wipe the diamond cell before start to do analyse. After that, adequate amount of the BPP was prepared and placed onto the diamond cell. The pressure town was screwed down and pushes the sample firmly against the crystal until the pressure gauge on the software program displays optimum level of pressure which around 70 – 80%. Normally, the ATR spectra analysis was measured within the wavelength range of $400 - 4000\text{ cm}^{-1}$ with a resolution of 4 cm^{-1} for 32 scans (Antton Paar, 2022). After done analyse the BPP, all the steps were repeated by replace different composition of PVA/BPP blend film.

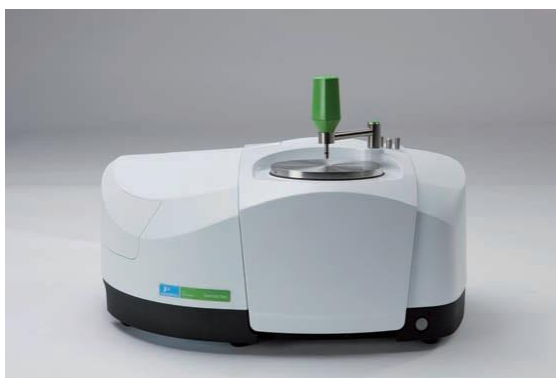


Figure 3.2: Perkin Elmer Spectrum Two.

3.7.2 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis is used to determine the thermal stability and volatility of the PVA/BPP blend film. The thermal stability that measures inside the PVA/BPP blend film which include filler content, residual solvent content, decomposition temperature, performance of stabilizer and more (Photometrics.net, 2019). TGA is weighted and change continuously the PVA/BPP blend film with a heat constant rate to get the result. Small piece of PVA/BPP blend film undergoes this analysis by using the nitrogen environment with a flow rate of $20\text{ mL}/\text{min}$ and the heating rate is constant which is $10\text{ }^{\circ}\text{C}/\text{min}$. Initially, the temperature is heated at 30°C , after that it will heat up until 600°C . The **Figure 3.3** shows the TGA analyser.



Figure 3.3: TGA Analyser.

3.7.3 Tensile Tester

The Tinius Olsen H10KS-0784 tensile tester was used to determine the tensile strength, elastic modulus, and elongation at break of PVA/BPP blend film. The dumbbell cutter was used to cut five dumbbell shaped specimens with the average thickness of 0.64 mm before the tensile test started. After that, the dumbbell shape specimen was test in the tensile tester at crosshead speed of 20 mm/min. The results of the tensile strength, elastic modulus and elongation at break were show at the stress-strain curves. The other 4 dumbbell shape specimens were repeated to get an average result. The **Figure 3.4** shows the Tinius Olsen H10KS-0784 tensile tester.



Figure 3.4: Tinius Olsen H10KS-0784 Tensile Testing Machine.

3.7.4 Biodegradability Test

Biodegradability test was performed through soil burial test. This test is to identify the biodegradability of non-biodegradable plastic bag film and PVA/BPP blend film. Biodegradability test interacts with oxygen, atmospheric pollutants and temperature variations which can degrade physical, mechanical, and chemical properties. First, the PVA/BPP blend films and normal plastic film were cut into dumbbell shape and the weight of the films were measured before buried inside the soil. After that, found the soil that rich of nitrogen. 200g of soil was measured and stored it in a container. The samples were buried inside the soil for 2 weeks under the room condition. The weightage of the films was measured and recorded every 1 week. The percentage of the degradation can be calculation by using **Equation 3.1** (Marichelvam, Jawaaid and Asim, 2019).

$$\text{Percentage of degradation, \%} = \frac{W_o - W}{W_o} \times 100\% \quad (\text{Equation 3.1})$$

Where:

W_o = *Weight of the film before test*

W = *Weight of the film after test*

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Characterization of Banana Peel Powder (BPP) and Polyvinyl Alcohol/Banana Peel Powder (PVA/BPP) Blend Films

Attenuated total reflectance spectroscopy (ATR), thermogravimetric analysis (TGA), biodegradability test and mechanical properties were carried out to characterize the PVA/BPP blend films. Besides, ATR also use to characterize the banana peel powder. However, there was insufficient time to get the result from the particle size analysis and energy dispersive x-ray because both of these are under maintenance.

4.1.1 Attenuated Total Reflectance Spectroscopy (ATR)

Attenuated total reflectance spectroscopy (ATR) was used to determine the functional group of BPP and PVA/BPP blend film. However, the functional group of BPP and PVA/BPP blend film were only shown in the region 1500 cm^{-1} and above while the region below 1500 cm^{-1} will show fingerprint region which is difficult to identify its functional group. Hence, the chemical properties of BPP and PVA/BPP blend film were determined in the region above 1500 cm^{-1} . **Figure 4.1** shows the spectra of ATR for BPP, and **Figure 4.2** shows the spectra of ATR for PVA/BPP blend film with different composition of glycerol. Meanwhile, **Table 4.1** shows the infrared absorption peaks of BPP and PVA/BPP blend films.

Figure 4.1 showed the broad peak at 3288 cm^{-1} which is correspond to O-H stretching related to intramolecular hydrogen bonds of cellulose. Meanwhile, the narrow peak at 2920 cm^{-1} and 2851 cm^{-1} represented C-H bond stretching in cellulose and hemicellulose of the banana peel (SHHRIM et al., 2018). Meanwhile, the peak of 1735 cm^{-1} and 1593 cm^{-1} are also consider narrow and it indicated functional group of C=O stretching and N-H bending respectively. Apart from that, **Figure 4.2** showed 3 different peaks for each of the PVA/BPP blend film with different composition of glycerol. For PVA/BPP blend film that without glycerol, it showed one board peak at 3277 cm^{-1} which indicated functional group of O-H stretching and two narrow peak at 2941 cm^{-1} and 1649 cm^{-1} were indicated C-H stretching and O-H bending respectively. For PVA/BPP blend film that with the presence of glycerol, it also showed similar peak as the PVA/BPP blend film that without glycerol with slightly different of wavelength. However, by comparing BPP and PVA/BPP blend film, it showed that BPP did not have the functional group of O-H bending but PVA/BPP blend film have it. Therefore, it indicated that BPP did not have hydroxyl group while PVA/BPP blend film have hydroxyl group due to the presence of glycerol in the film and showed the characteristics of alcohol. Moreover, PVA/BPP blend film did not have the functional group of C-H stretching, C=O stretching and N-H bending but BPP have all these functional group. The reason that PVA/BPP blend film did not have these functional group is because the C-O in C=O stretching is involved in the hydrogen bond formation and formed more stable hydrogen bond. Hence, it resulted that PVA/BPP blend film have hydroxyl group. Last but not least, the functional group of N-H bending for BPP is showed due to the characteristics of amine group (Zheng and Wang, 2013).

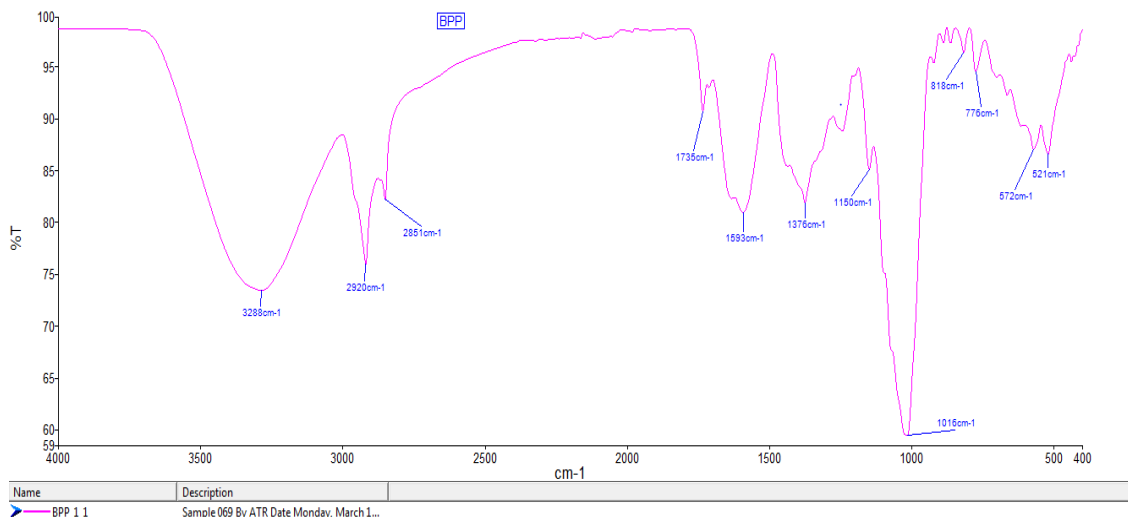
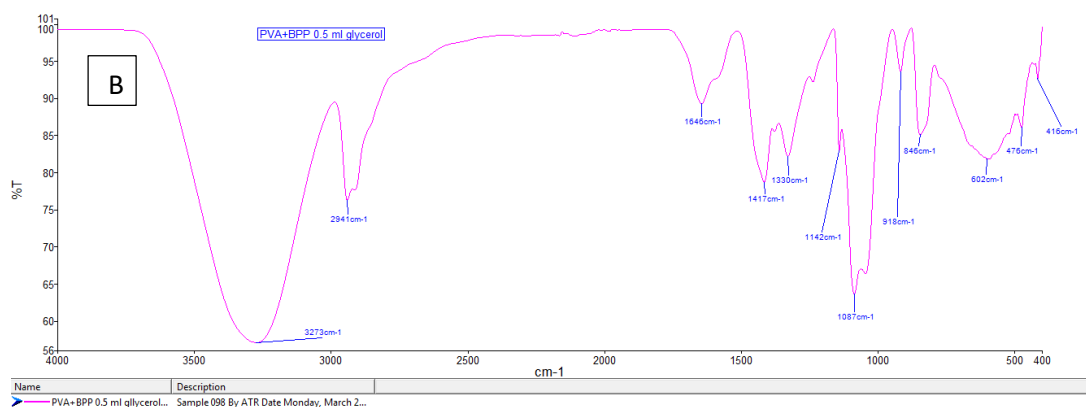
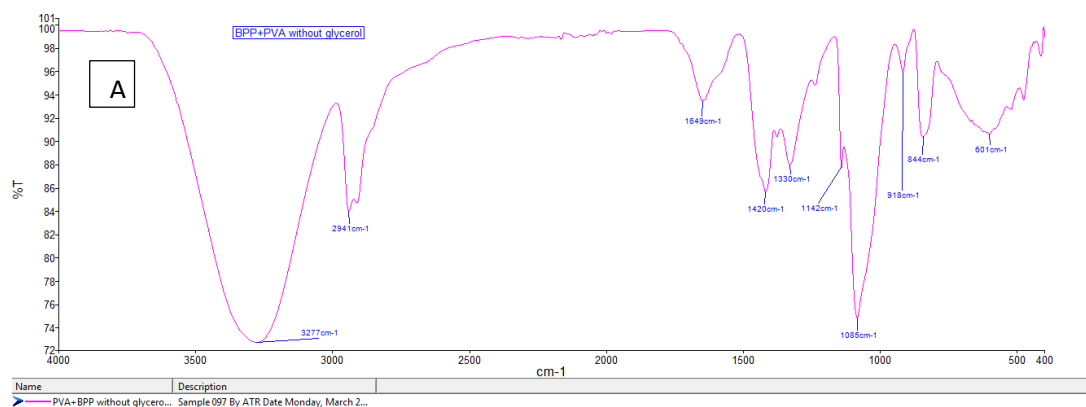


Figure 4.1: Spectra of ATR for BPP.



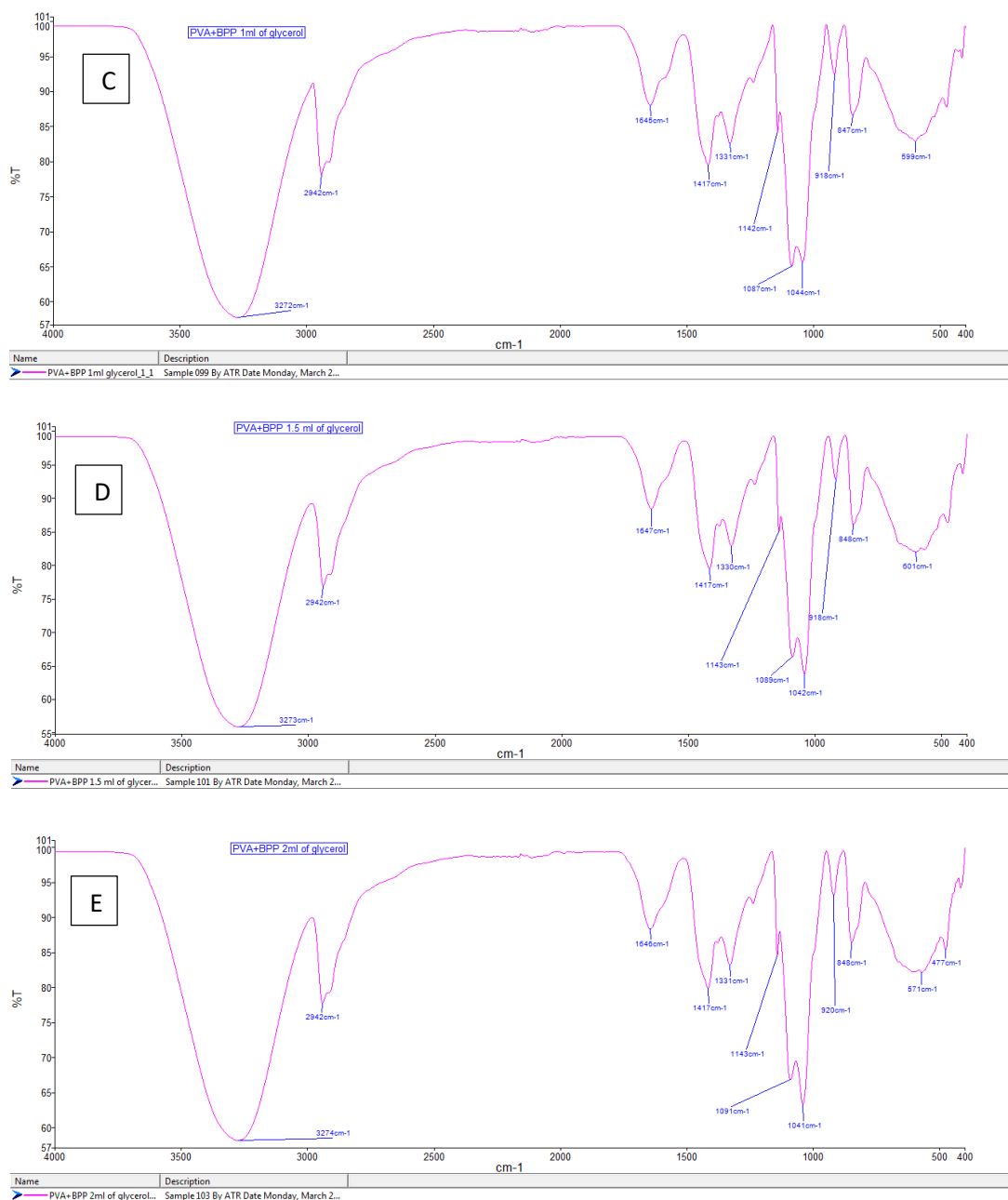


Figure 4.2: Spectra of ATR for PVA/BPP Blend Films with Different Composition of Glycerol (**A:** PVA/BPP blend film without glycerol, **B:** PVA/BPP blend film 0.5ml of glycerol, **C:** PVA/BPP blend film 1.0ml of glycerol, **D:** PVA/BPP blend film 1.5ml of glycerol and **E:** PVA/BPP blend film 2.0ml of glycerol)

Table 4.1: Infrared Absorption Peaks of BPP and PVA/BPP Blend Films.

Wavelength, cm^{-1}						Functional Group
BPP	PVA/BPP without glycerol	PVA/BPP 0.5 ml of glycerol	PVA/BPP 1.0 ml of glycerol	PVA/BPP 1.5 ml of glycerol	PVA/BPP 2.0 ml of glycerol	
3288	3277	3273	3272	3273	3274	O-H stretching
2920	2941	2941	2942	2942	2942	C-H stretching
2851	-	-	-	-	-	C-H stretching
1735	-	-	-	-	-	C=O stretching (ester)
-	1649	1646	1645	1647	1646	O-H bending
1593	-	-	-	-	-	N-H bending

4.1.2 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis (TGA) was used to determine the thermal properties for PVA/BPP blend films. There are three main stage of weight loss for PVA/BPP blend film. The first stage is about 100°C which the evaporation of moisture content will happen in this stage. The example for moisture content is water and glycerol. The second stage of weight loss was allocated at the temperature between 200°C to 300°C where the PVA/BPP blend film was decomposed by the PVA and BPP due to the thermal decomposition of the polymer backbone. Meanwhile, the last stage of weight loss was between 380°C to 500°C. This stage was occurred due to the degradation of the byproducts which generated by PVA during the thermal degradation happened (Choo et al., 2016).

Figure 4.3 shows the TGA result for all the PVA/BPP blend film. It showed that the weight loss will increase when the composition of glycerol is increasing. Meanwhile, the thermal stability of PVA/BPP blend film is decreasing. This is because the lignin and hemicellulose structure were removed and it will make the cellulose

easier to degrade and loss weight when BPP blended with the PVA (Othman et al., 2011).

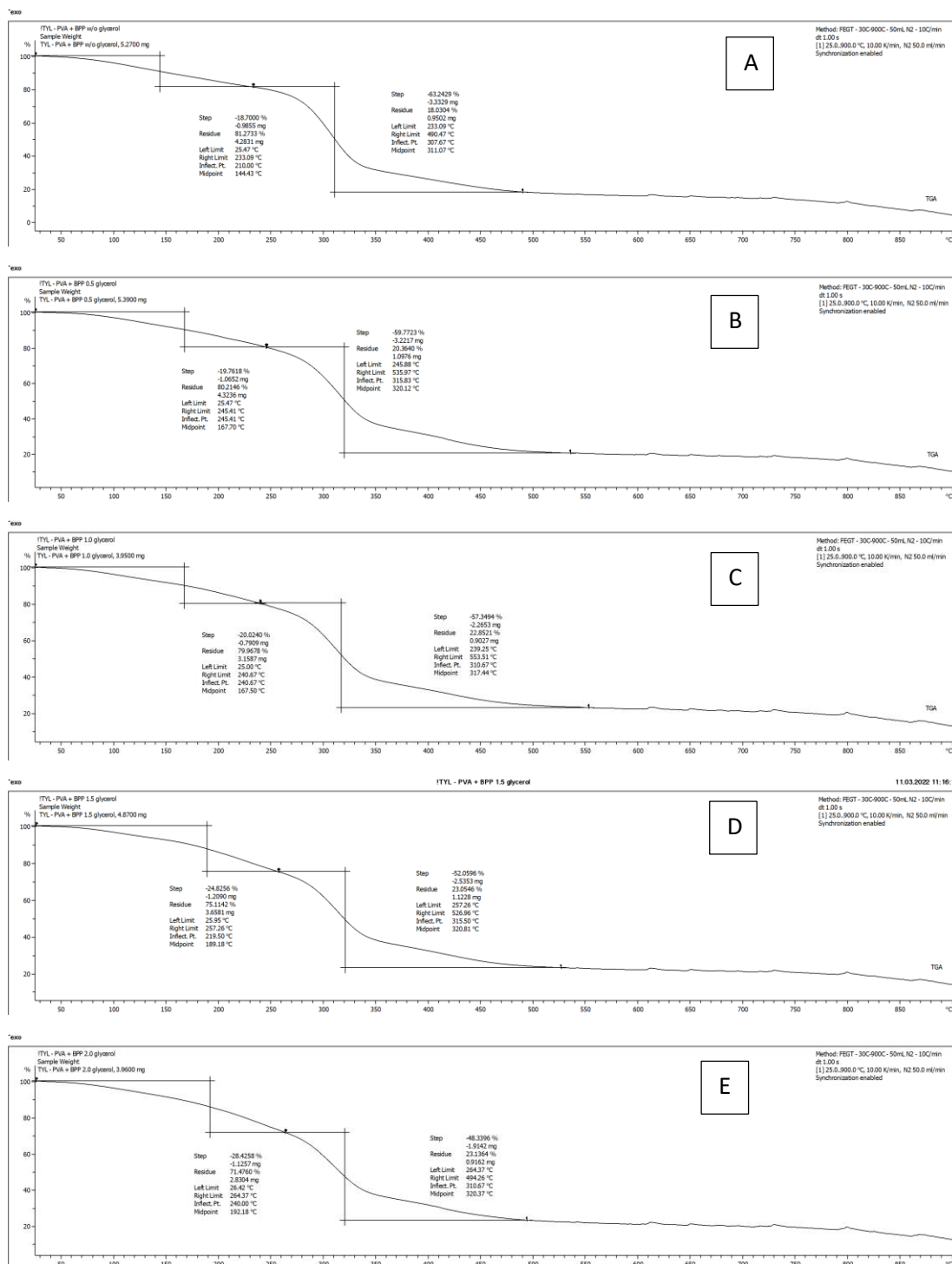


Figure 4.3: TGA Result of PVA/BPP Blend Films (**A:** PVA/BPP blend film without glycerol, **B:** PVA/BPP blend film 0.5ml of glycerol, **C:** PVA/BPP blend film 1.0ml of glycerol, **D:** PVA/BPP blend film 1.5ml of glycerol and **E:** PVA/BPP blend film 2.0ml of glycerol).

4.1.3 Mechanical Properties

Different composition of PVA/BPP blend film were cut into dumbbell shape and the thickness of all PVA/BPP blend film were measured by using the digital micrometer. The range of the thickness of PVA/BPP blend film is between 0.460mm to 0.820mm. After that, mechanical properties for all the PVA/BPP blend films were carried out 5 times and get the average result for tensile strength, elongation at break and elastic modulus.

Figure 4.4 showed the result of tensile strength for all the PVA/BPP blend film. The tensile strength of PVA/BPP blend film that without the glycerol was 6.65 ± 0.49 MPa while the tensile strength of PVA/BPP blend film that contain 0.5ml of glycerol was 4.318 ± 0.46 MPa. Meanwhile, the tensile strength for the film that contain 1.0ml, 1.5ml and 2.0ml of glycerol were 4.013 ± 0.45 MPa, 3.663 ± 0.48 MPa and 3.616 ± 0.29 MPa. From this result, it can be concluded that when the plasticizer which is glycerol, was added into the PVA/BPP blend film, the tensile strength of the film were decrease drastically as the amount of the plasticizer were increase.

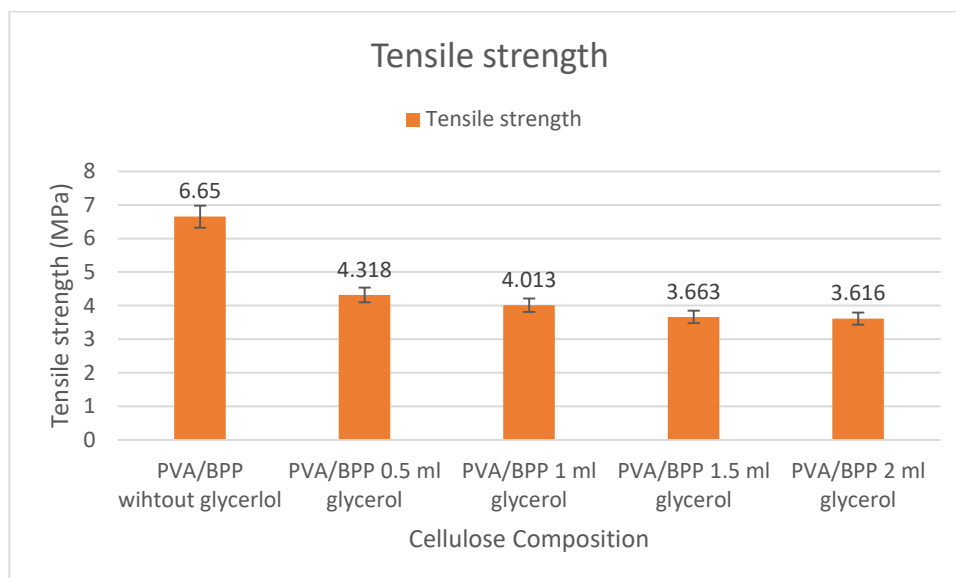


Figure 4.4: Tensile Strength of PVA/BPP Blend Films.

In addition, the elongation at break is opposite with the tensile strength. According to the result that showed in **Figure 4.5**, the PVA/BPP blend film that

without glycerol had the lowest percent of elongation at break which is $32.72 \pm 2.94\%$. When the glycerol was added into the blend film, the elongation at break is increasing as the amount of glycerol increased. In this project, the elongation at break for PVA/BPP blend film that contain 0.5ml of glycerol is $34.27 \pm 4.76\%$. Furthermore, the elongation at break also increases from $34.27 \pm 4.76\%$ to $35.74 \pm 5.25\%$, $36.11 \pm 5.51\%$ and $48.31 \pm 8.27\%$ when the amount of glycerol was increasing every 0.5ml until 2.0ml for each blende film.

When increase the amount of glycerol, the tensile strength of the blend film will decrease while the elongation at break will increase. It is because the intermolecular bond between PVA molecule is replace by the intermolecular bond between PVA and glycerol. Hence, the strength of the bond will decrease which can cause the blended film easier to break. However, the tensile strength decreases slowly because both of the intermolecular bond between PVA molecule and intermolecular bond between PVA and glycerol are linked by the hydrogen bond (Dianursanti, Gozan and Noviasari, 2018).

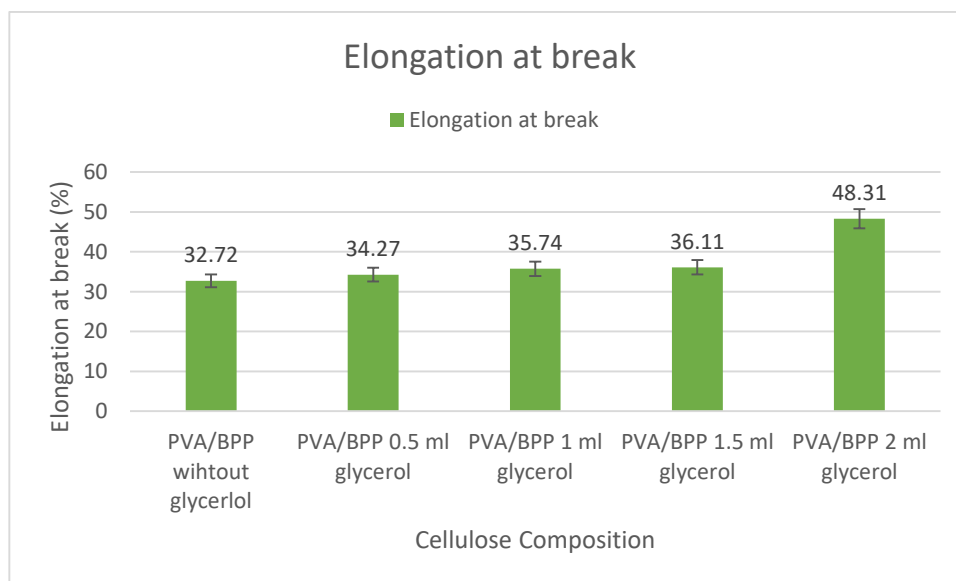


Figure 4.5: Elongation at Break of PVA/BPP Blend Films.

Elastic modulus had similar trend with tensile strength which is the elastic modulus will decrease when increase the amount of plasticizer into the blend films. **Figure 4.6** had shown the e-modulus decrease significantly as the amount of glycerol is increased. The blended film that without glycerol had the highest e-modulus which is $81.9 \pm 11.40\text{MPa}$ followed by 0.5ml, 1.0ml, 1.5ml and 2.0ml of glycerol. E-modulus

is 49.99 ± 8.70 MPa when the 0.5ml of glycerol was added into the PVA/BPP blend film. Besides that, the e-modulus decrease continuously, which from 43.59 ± 5.68 MPa to 30.85 ± 4.99 MPa and 30.14 ± 2.43 MPa when 1.0ml, 1.5ml and 2.0ml of glycerol were added into the PVA/BPP blend film. When increase the e-modulus of the PVA/BPP blend film, the stiffness also will increase. This is because the amount of the plasticizer which is glycerol play an important role to provide better elastic modulus. When the PVA/BPP blend film contain larger amount of glycerol, it has higher resistance to elastic deformation and less stretch when some force was applied it (Suki et al., 2014).

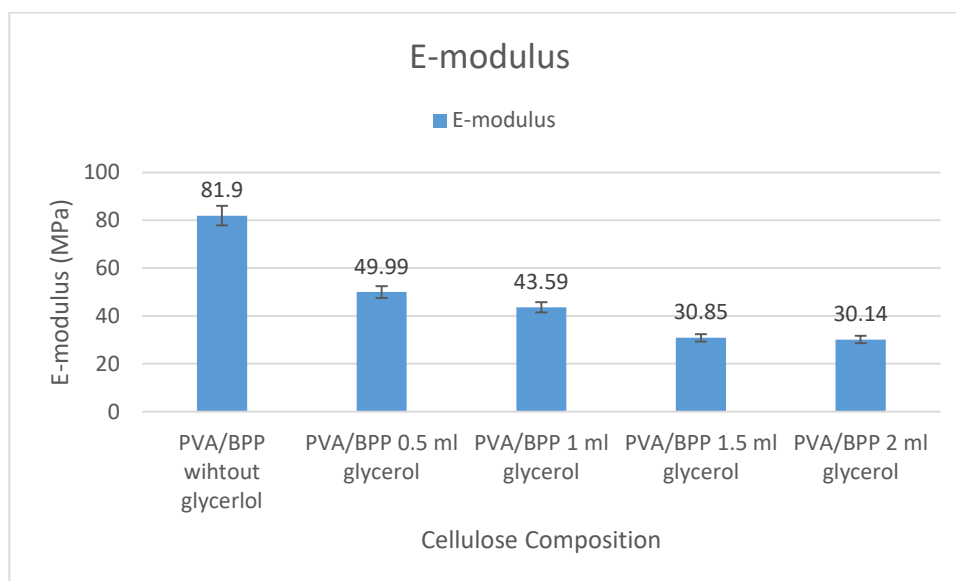


Figure 4.6: E-modulus of PVA/BPP Blend Films.

In a nutshell, the tensile strength, elongation at break and elastic modulus are interrelated with each other. This is because tensile strength will affect the elongation at break because the intermolecular bonds between PVA molecules were replaced by intermolecular bonds between PVA and glycerol. When the elongation at break is affected, the elastic modulus also will be affected because the change of intermolecular bonds can cause a reduction in stiffness and an increase in the flexibility of the blended film. Hence, tensile strength, elongation at break, and elastic modulus of the PVA/BPP blend film will affect each other (Dianursanti, Gozan and Noviasari, 2018).

4.1.4 Biodegradability Test

Biodegradability test also known as soil burial test where it is a type of test that used to determine the biodegradability of the material. This test undergoes in natural situation such as rainfall, sunlight, humidity moisture, UV radiation and more. **Figure 4.7** shows that the soil burial test was carried out in 2 weeks for non-biodegradable plastic bag film and PVA/BPP blend film with different composition of glycerol which are 0ml, 0.5ml, 1.0ml, 1.5ml and 2.0ml. The purpose of compare PVA/BPP blend film and non-biodegradable plastic bag film is to determine the biodegradability blend film with the non-biodegradable plastic bag film.

Figure 4.7 shows the result of biodegradability test for all the film. After 1 week of this test, PVA/BPP blend film which contain 1.5ml of glycerol has highest biodegradability which is 6.77% and followed by 0.5ml, 2.0ml, 1.0ml and 0ml of glycerol blended film, which are 6.67%, 5.60%, 5.04% and 4.69% respectively. Then, all these blend films undergo biodegradability test continuously to the following week. At the end of week 2, the result showed that PVA/BPP blend film which contain 2 ml of glycerol has highest biodegradability which is 11.55%. Meanwhile, PVA/BPP blend film that without glycerol has lowest degradation rate as compared to other which only has 4.46%. Furthermore, PVA/BPP blend film which contain 0.5ml of glycerol was degrade about 9.94% followed by 1.5ml and 1.0ml, which are 9.41% and 6.36% respectively. Apart of the PVA/BPP blend film, non-biodegradable plastic bag film which normally can found in market also had undergo this biodegradability test. From the **Figure 4.7**, it showed that non-biodegradable plastic bag film has no degradation rate along this 2 week. The reason of the non-biodegradable plastic bag film did not have degradation rate is because it is made up of petroleum-based plastic and it need longer time to degrade compare with the biodegradable plastic.

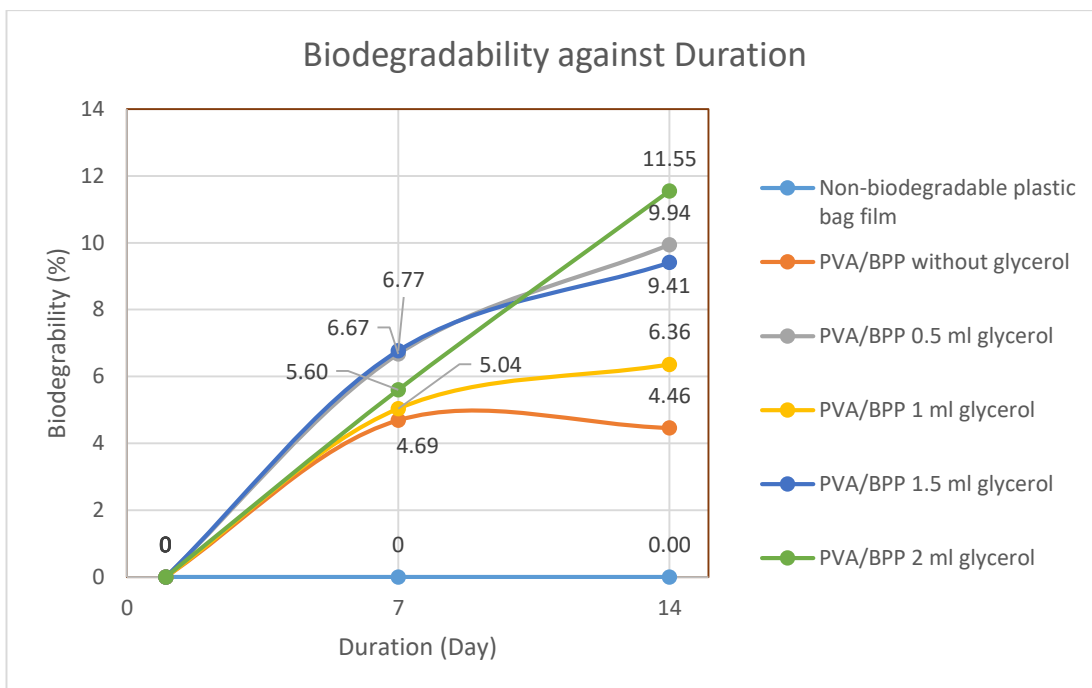


Figure 4.7: Result of Biodegradability Test.

The physical appearances of all the film were shown in **Figure 4.8** to **Figure 4.13**. According to the result that showed in **Figure 4.8** to **Figure 4.12**, all the PVA/BPP blend film were shrunk after two weeks of the biodegradability test. Annealing effect was happened due to the blended films can shrink and swell easily. PVA/BPP blend film will shrink when it exposed to the sunlight. Meanwhile, PVA/BPP blend film will swell due to the blended film is hydrophilic polymer and it can absorb water during the rain session (Suki et al., 2014). When shrink and swell happened, it can cause cracking on the surface of the blended films which shown in **Figure 4.12**. Apart from the PVA/BPP blend film, the non-biodegradable plastic bag film remains unchanged according to its physical appearances which shown in **Figure 4.13**. Hence, biodegradability of PVA/BPP blend films were proven as compare with non-biodegradable plastic bag film.

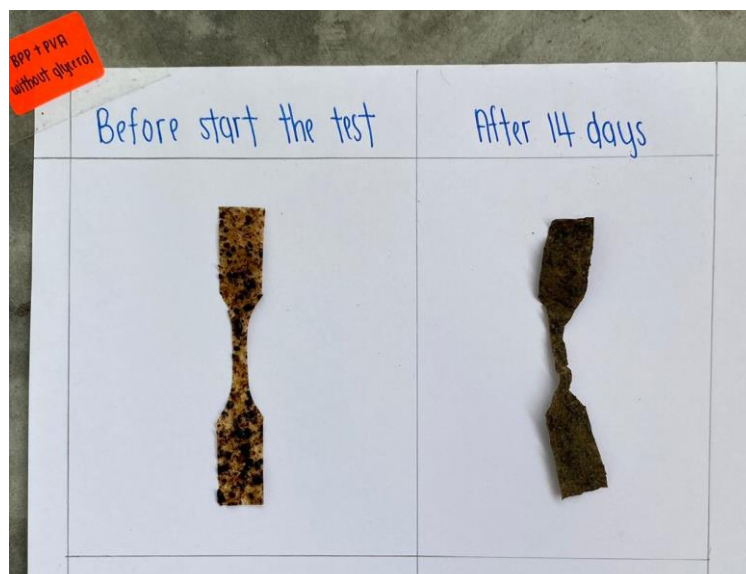


Figure 4.8: Biodegradability Test for PVA/BPP Blend Film without glycerol

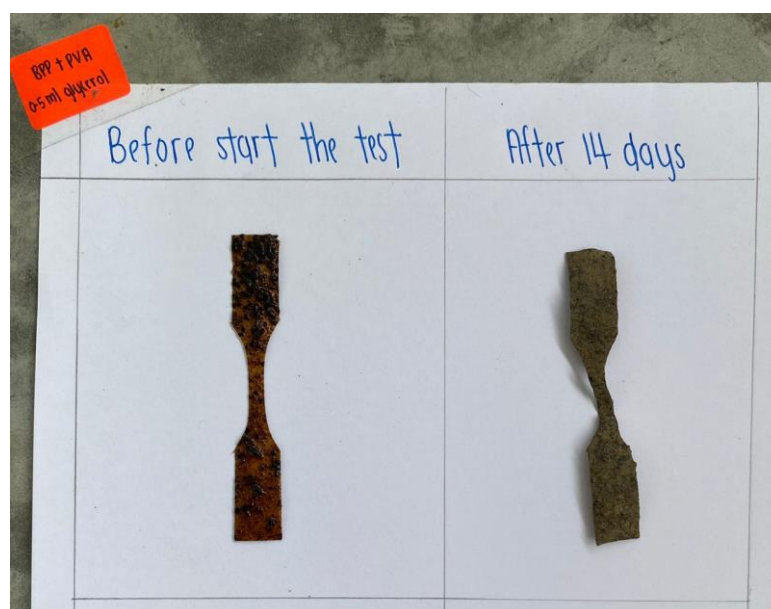


Figure 4.9: Biodegradability Test for PVA/BPP Blend Film 0.5ml of glycerol

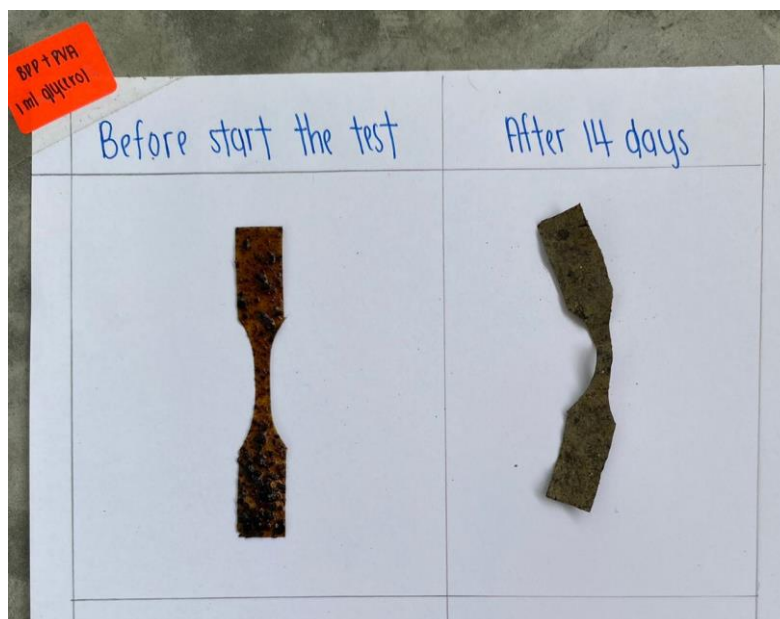


Figure 4.10: Biodegradability Test for PVA/BPP Blend Film 1.0ml of glycerol

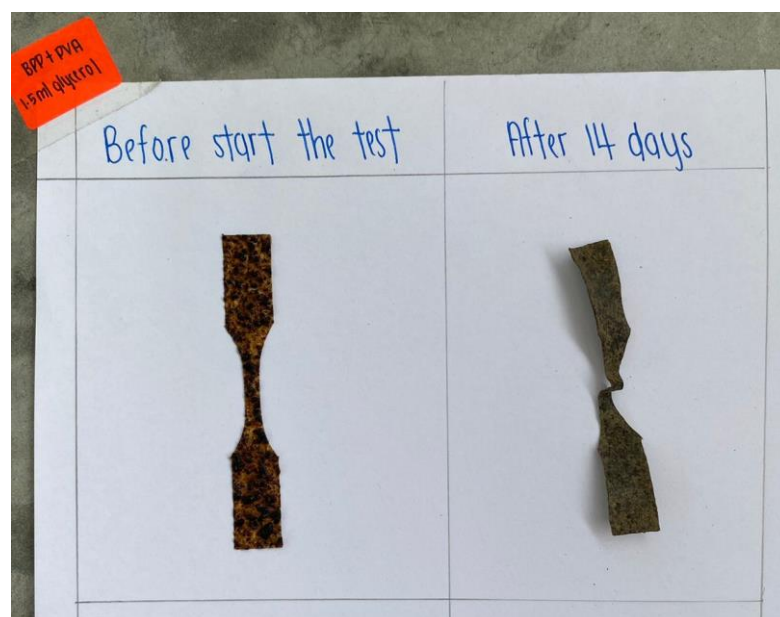


Figure 4.11: Biodegradability Test for PVA/BPP Blend Film 1.5ml of glycerol

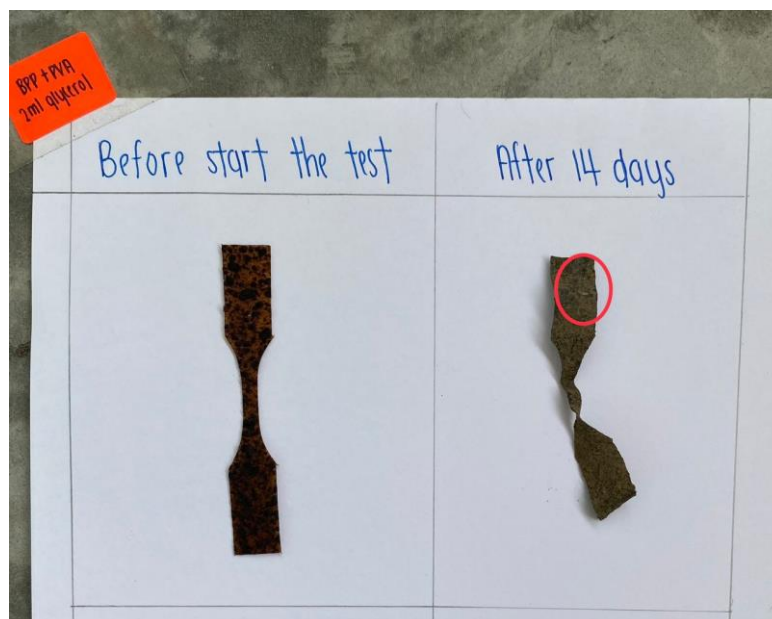


Figure 4.12: Biodegradability Test for PVA/BPP Blend Film 2.0ml of glycerol

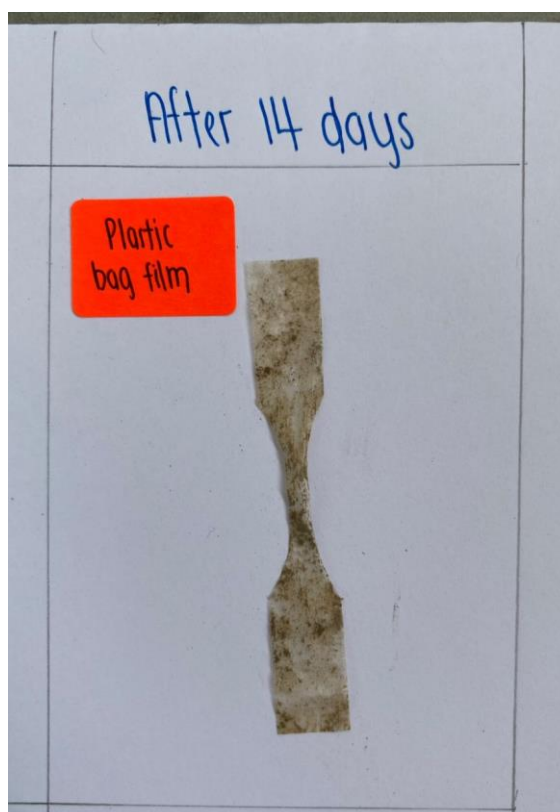


Figure 4.13: Biodegradability Test for Non-biodegradable Plastic Bag Film

The two reasons that may occur when the glycerol leaches from the films which are strong affinity of glycerol towards water and absorption of glycerol by the soil. This is because water acts as a strong driving force to leach the glycerol out from the film to soil moisture. Besides, films which contain glycerol will be absorbed by the soil to increase the bioavailability of the soil water. When the glycerol content increases to 20%, it will improve the mechanical properties and the biodegradation rate will reduce slightly. However, when the glycerol content increases up to 20%, the mechanical properties and biodegradability were reversed. This study had the same principle with this theory as the PVA/BPP blend film that without glycerol and 0.5ml of glycerol reduced the biodegradability rate slightly. When the glycerol content increases up to 20% which is 1.0ml of glycerol, it will increase the biodegradability rate significantly. There are several reasons that might affect the result of biodegradability test. First, the soil will stick onto the film which may increase the weight of film during the measurement. Next, some piece of film may lose in the soil and the microorganism colonies will form on the film which are very difficult to clean it. However, these can be avoided when the procedure is done completely (Ostadi et al., 2020). Lastly, the dispersion of glycerol in the PVA/BPP blend film might affect its biodegradability rate as well. Since the mixing time for all the PVA/BPP blend films is constant, the resulting blend film might face suspension when the loading of glycerol in the blend film is low and thus, the blend film will tend to degrade in a short period of time. However, if the loading of glycerol in the blend film gets increased, the biodegradability rate depends on the dispersion of glycerol in the blend film. If the blend film is well dispersed, the blend film might need longer time to start degrading. If the blend film is unwell dispersed, the blend film will tend to degrade with a shorter time period.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Study

In this research, the effect of glycerol on the mechanical properties of polyvinyl alcohol/banana peel powder (PVA/BPP) blend film was accomplished successfully. Solution casting method was the main process to form the blended film throughout this research. Besides, one-factor-at-a-time (OFAT) method was used to fix the weightage of polyvinyl alcohol (PVA) and banana peel powder (BPP) as well as change the weightage of glycerol during this research. After that, the characterization of BPP and PVA/BPP blend film was carried out through Attenuated Total Reflectance spectroscopy (ATR), thermogravimetric analysis (TGA), tensile test and biodegradability test.

During the ATR analysis, the functional group of BPP and PVA/BPP blend film was determine and differentiate successfully. BPP have the functional group of O-H stretching which allocate at the peak of 3288 cm^{-1} and it indicates intramolecular hydrogen bond of cellulose. Other than that, the peak that showed at 2920 cm^{-1} and 2851 cm^{-1} which indicated C-H bond stretching in cellulose and hemicellulose of BPP. Thus, the objective 1 is achieved.

Tensile test was carried out to determine the mechanical properties of PVA/BPP blend film by using different composition of glycerol. Tensile strength and elastic modulus had the similar trend, which is the tensile strength and elastic modulus will decrease as the composition of glycerol is increased. Meanwhile, the elongation at break is reversed where it will increase when the composition of glycerol is decreased. Tensile strength, elongation at break and elastic modulus are interrelated

with each other and it will be affected when either one of them had any changes. From this statement, objective 2 also achieved throughout this research.

Biodegradability test was also carried out to determine the biodegradable properties of PVA/BPP blend film by using different composition of glycerol and non-biodegradable plastic bag film. PVA/BPP blend film with contain 2.0ml of glycerol has the highest biodegradation rate which is 11.55% while the PVA/BPP blend film without glycerol has the lowest biodegradation rate which is 4.46% as compare with other PVA/BPP blend film. Meanwhile, the biodegradation rate of the non-biodegradable plastic bag film is remaining the same which is 0% along these 2 weeks of experiment. From this result, the objective 3 is achieved which to evaluate the biodegradable properties of PVA/BPP blend film with different composition of glycerol.

5.2 Recommendation for Future Study

Throughout the results and discussions of this research project, there are several aspects that can be modified or improve the hand skill in order to improve the results and the quality of this research project. There are several recommendations are listed as below:

- i. During preparation of PVA/BPP blend film, BPP can blended finer in order to make sure the film able to mix uniformly with the PVA as well as the glycerol.
- ii. When pouring the PVA/BPP solution into the glass plate, ensure the solution is poured uniformly throughout the glass plate so that the thickness of the PVA/BPP blend film can be uniform.
- iii. Further characterizations of the BPP and PVA/BPP blend films can be performed by using Energy Dispersive X-Ray (EDX), Particle Size Analysis (PSA), Field Emission Scanning Electron Microscopy (FESEM), water permeability test and more characterization.

- iv. Different types of plasticizers, additives and crosslinking agents can be studied to determine the mechanical properties of PVA/BPP blend films.
- v. For the biodegradability test, the duration for degradation of the PVA/BPP blend film can be extended in order to allow the blended film to have enough time to degrade it in the soil.
- vi. Further analysis on the biodegradability test can be done perfectly by using the soil which contain rich nutrients and make sure the soil is in same condition for every blended films.
- vii. Further analysis on the biodegradability test can be done such as undergoes ATR to determine the functional group after degradation, FESEM can be done by observe the type of microorganisms that grow on the surface and mechanical properties of the PVA/BPP blend films.
- viii. Use control soil in biodegradability test in order to accurate the result of biodegradability test.

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APPENDICES

APPENDIX A: Mechanical Properties

A. Tensile strength for PVA/BPP blend film in different composition of glycerol, MPa

PVA/BPP	1 st	2 nd	3 rd	4 th	5 th	Mean	Standard derivation	Square root of number	Standard error mean
Without glycerol	7.25	6.95	6.61	7.65	4.81	6.65	1.101	2.2361	0.4924
0.5ml of glycerol	4.830	5.056	4.225	2.582	4.895	4.318	1.020	2.2361	0.4562
1.0ml of glycerol	4.941	2.350	3.939	2.855	3.466	4.013	1.001	2.2361	0.4477
1.5ml of glycerol	4.297	4.327	4.538	2.141	2.778	3.663	1.084	2.2361	0.4848
2.0ml of glycerol	3.999	2.548	3.943	3.659	4.165	3.616	0.649	2.2361	0.2902

B. E-modulus for PVA/BPP blend film in different composition, MPa

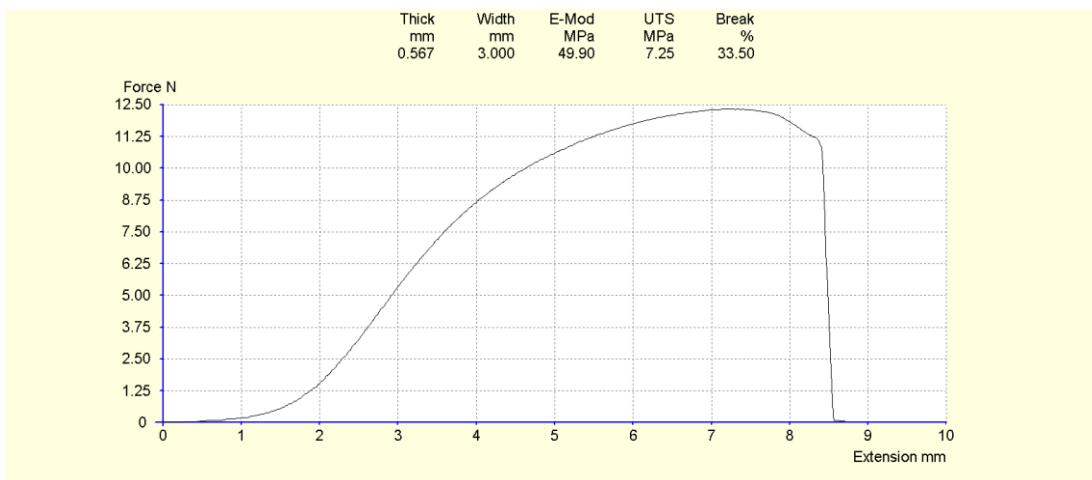
PVA/BPP	1 st	2 nd	3 rd	4 th	5 th	Mean	Standard derivation	Square root of number	Standard error mean
Without glycerol	49.90	76.40	120.90	84.40	78.00	81.90	25.49	2.2361	11.3993
0.5ml of glycerol	52.09	73.60	52.09	19.82	52.36	49.99	19.25	2.2361	8.6987
1.0ml of glycerol	39.00	13.10	24.95	19.30	21.84	43.59	12.69	2.2361	5.6751
1.5ml of glycerol	35.64	35.61	44.45	19.05	19.50	30.85	11.16	2.2361	4.9908
2.0ml of glycerol	33.10	32.41	20.44	32.91	31.82	30.14	5.44	2.2361	2.4328

C. Elongation at break for PVA/BPP blend film in different composition, %

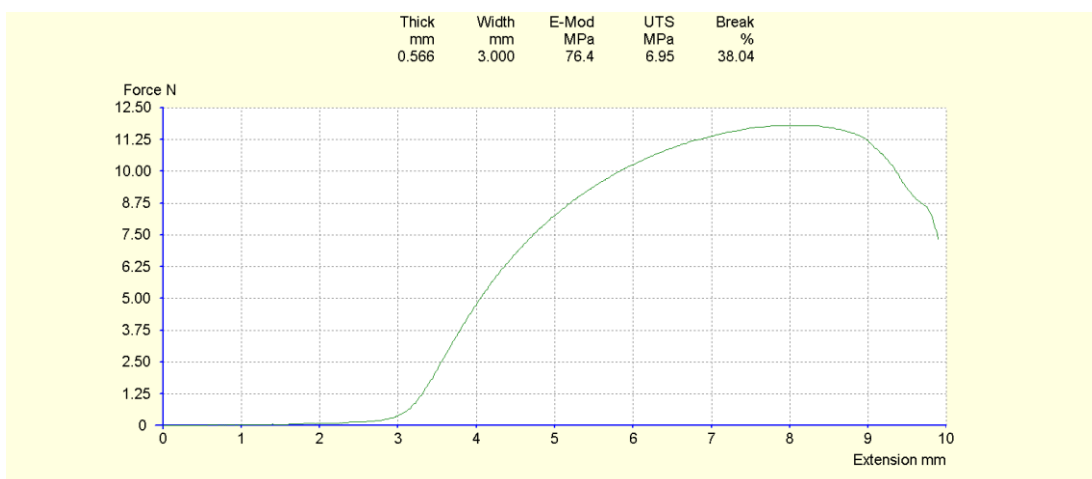
PVA/BPP	1 st	2 nd	3 rd	4 th	5 th	Mean	Standard derivation	Square root of number	Standard error mean
Without glycerol	33.50	38.04	33.23	37.23	21.61	32.72	6.58	2.2361	2.9426
0.5ml of glycerol	52.67	23.54	29.51	27.26	38.37	34.27	10.65	2.2361	4.7628
1.0ml of glycerol	51.92	35.00	31.00	44.23	56.54	35.74	11.73	2.2361	5.2457
1.5ml of glycerol	53.08	37.15	28.55	23.42	38.37	36.11	12.31	2.2361	5.5051
2.0ml of glycerol	51.92	26.51	55.38	34.27	73.46	48.31	18.49	2.2361	8.2689

D. Mechanical properties graph for PVA/BPP blend film without glycerol

1st for mechanical properties



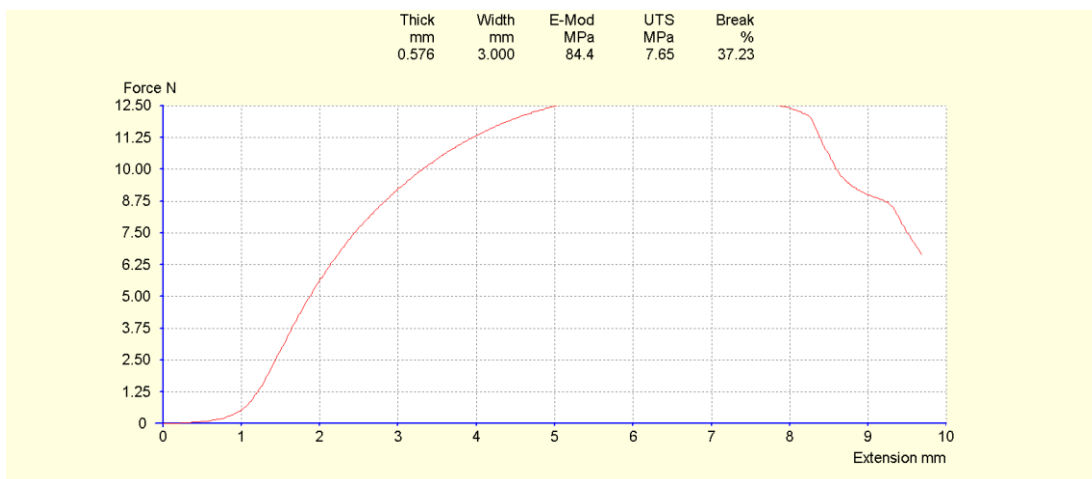
2nd for mechanical properties



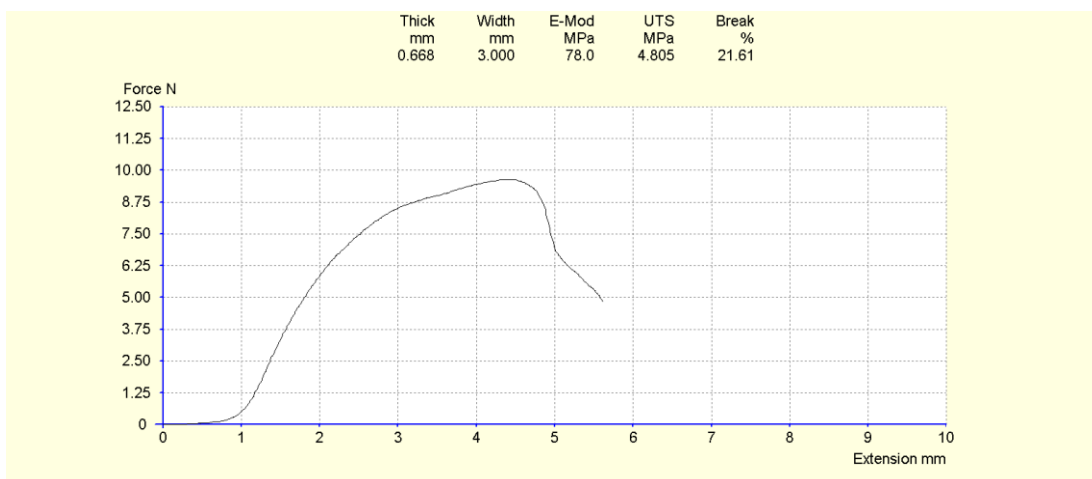
3rd for mechanical properties



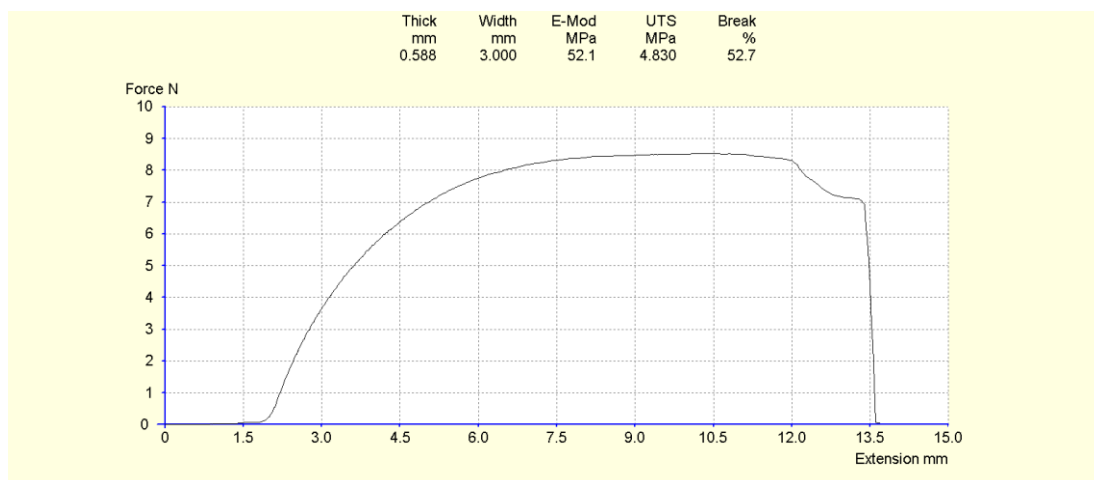
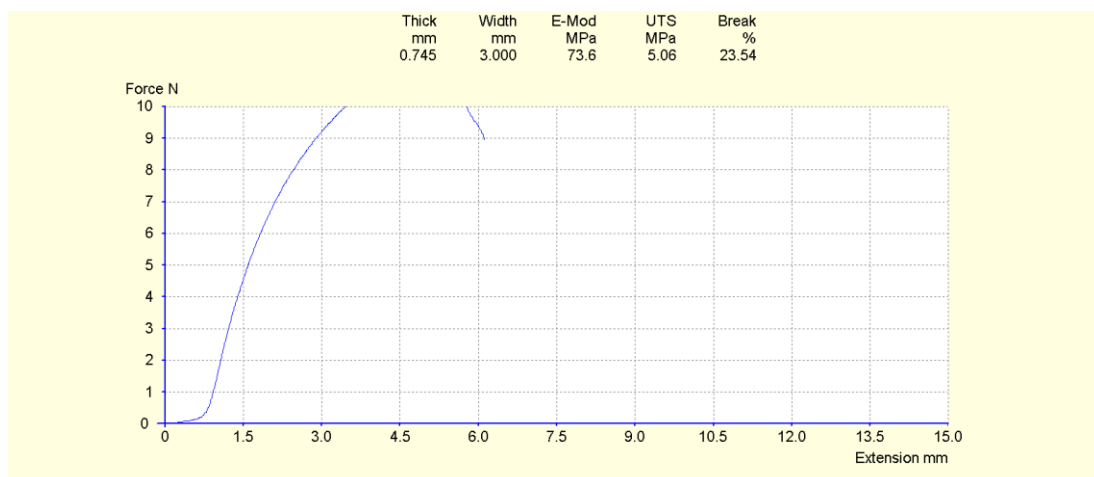
4th for mechanical properties

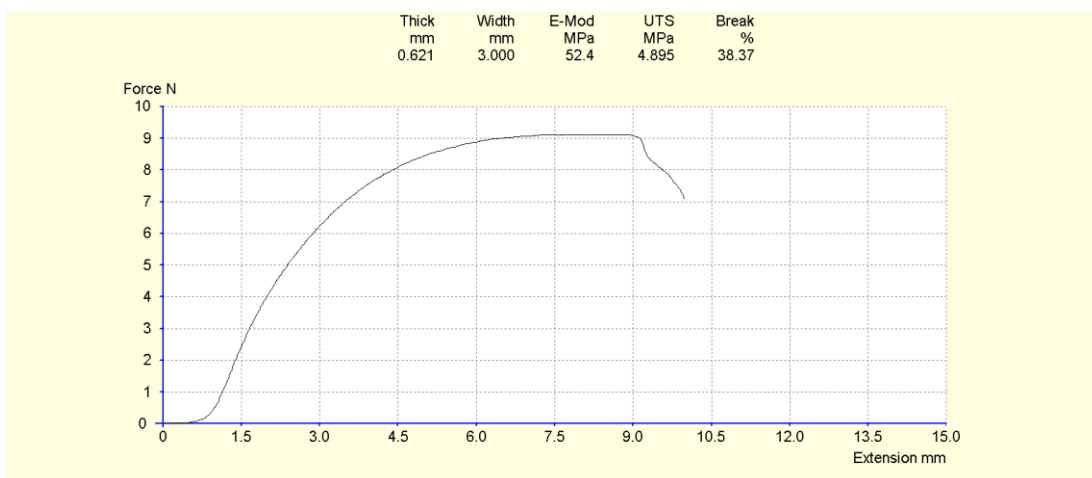


5th for mechanical properties



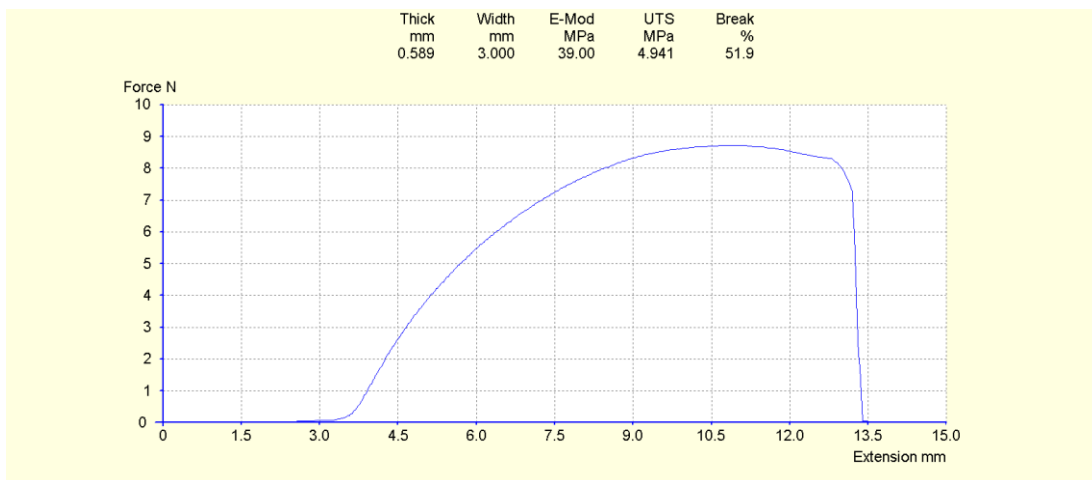
E. Mechanical properties graph for PVA/BPP blend film 0.5ml of glycerol

1st for mechanical properties2nd for mechanical properties

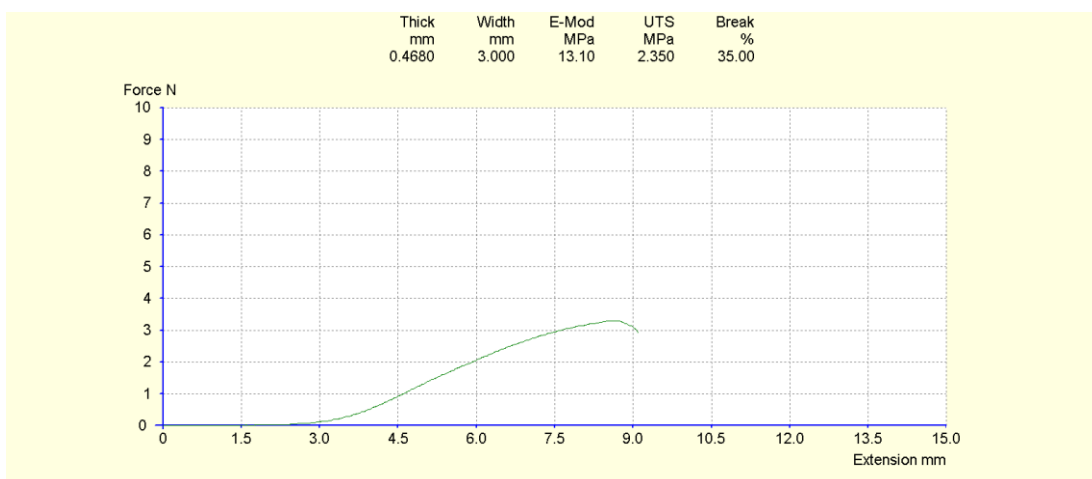
3rd for mechanical properties4th for mechanical properties5th for mechanical properties

F. Mechanical properties graph for PVA/BPP blend film 1.0ml of glycerol

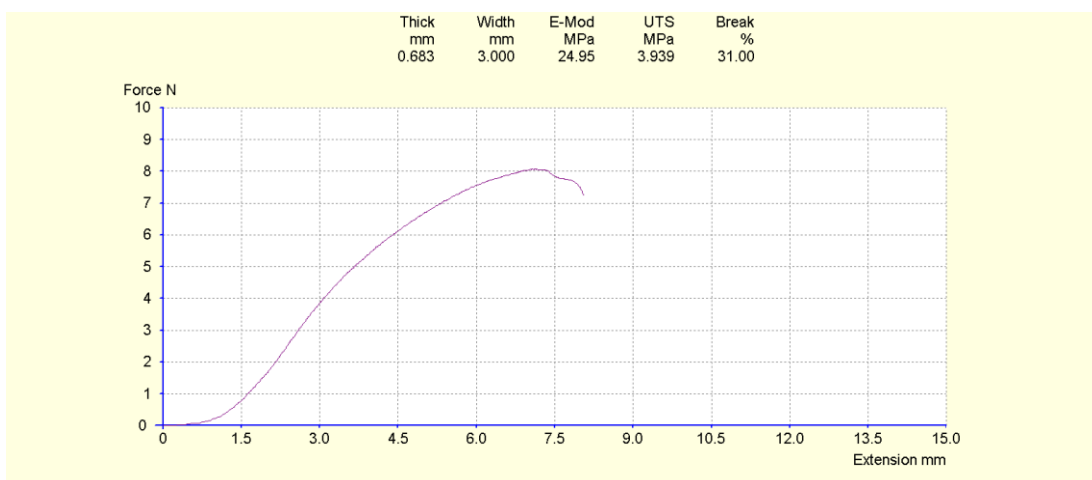
1st for mechanical properties



2nd for mechanical properties



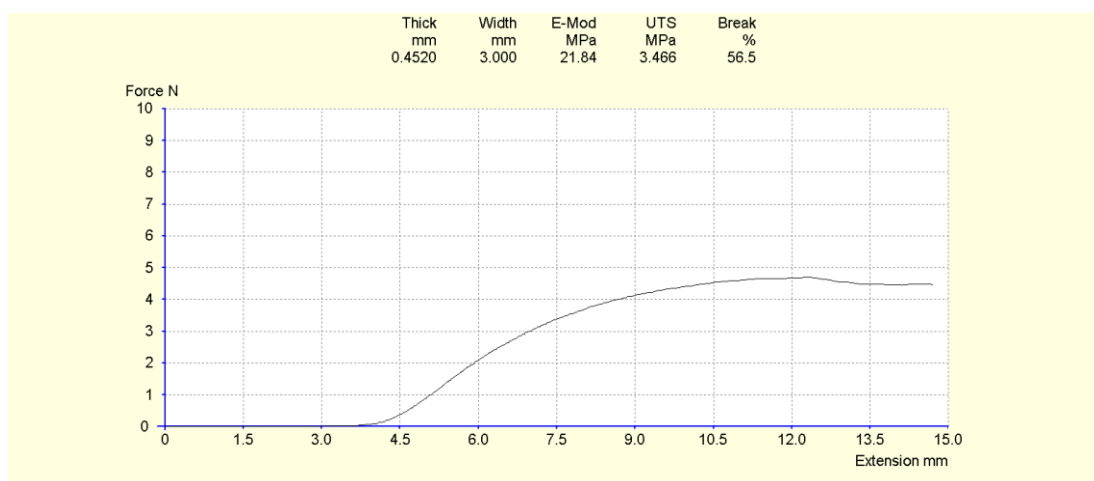
3rd for mechanical properties



4th for mechanical properties

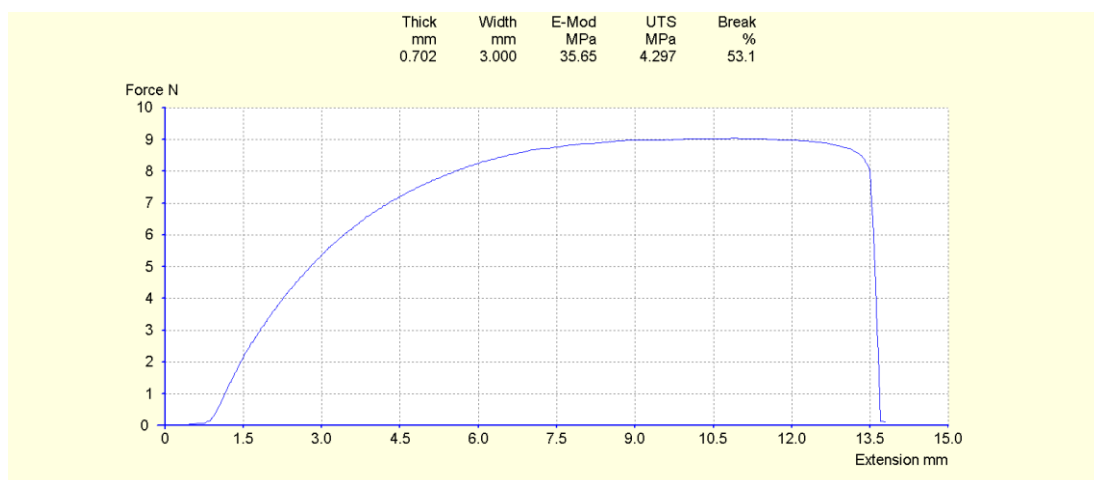


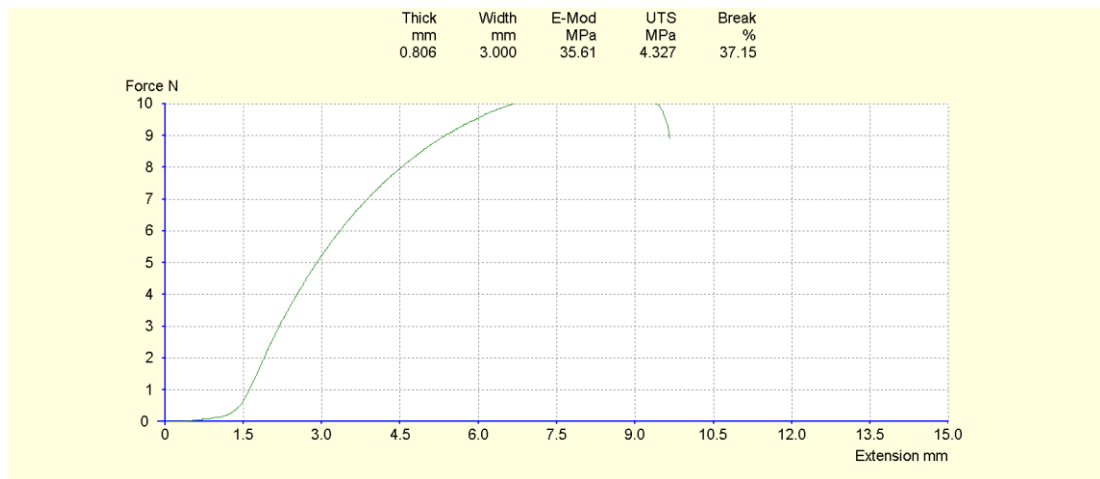
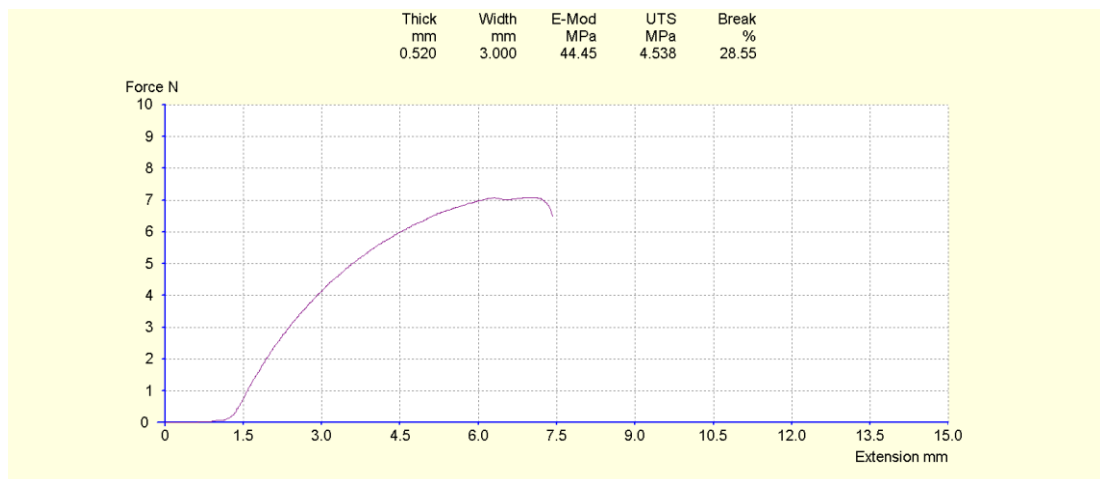
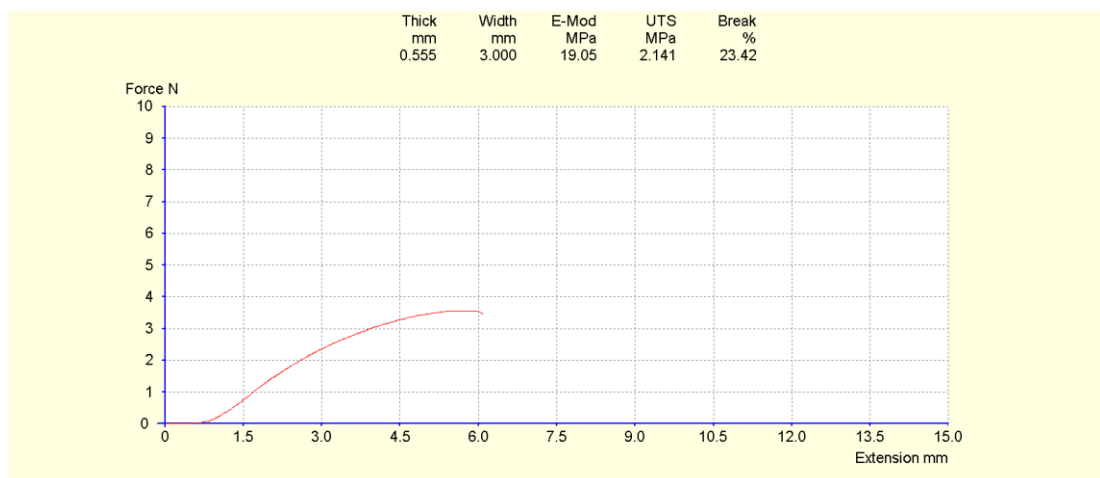
5th for mechanical properties



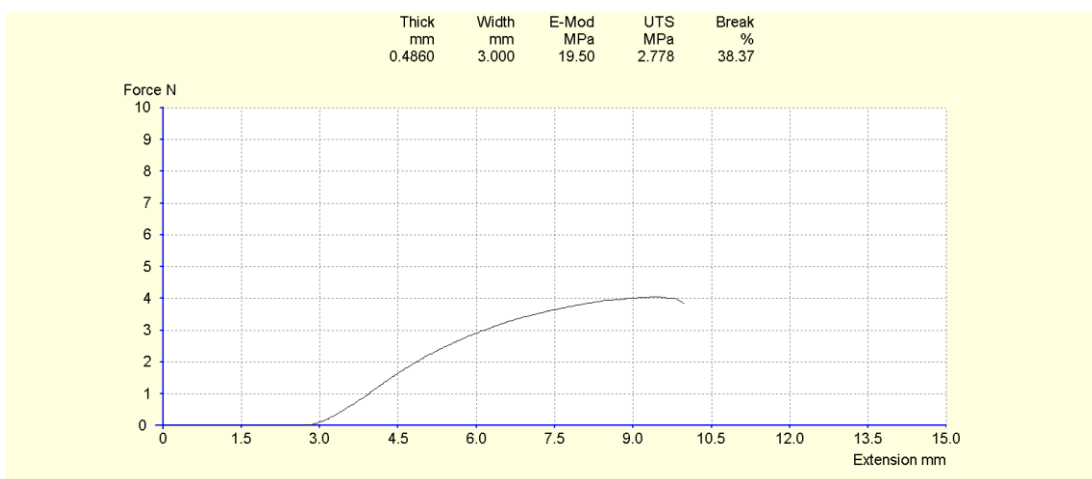
G. Mechanical properties graph for PVA/BPP blend film 1.5ml of glycerol

1st for mechanical properties



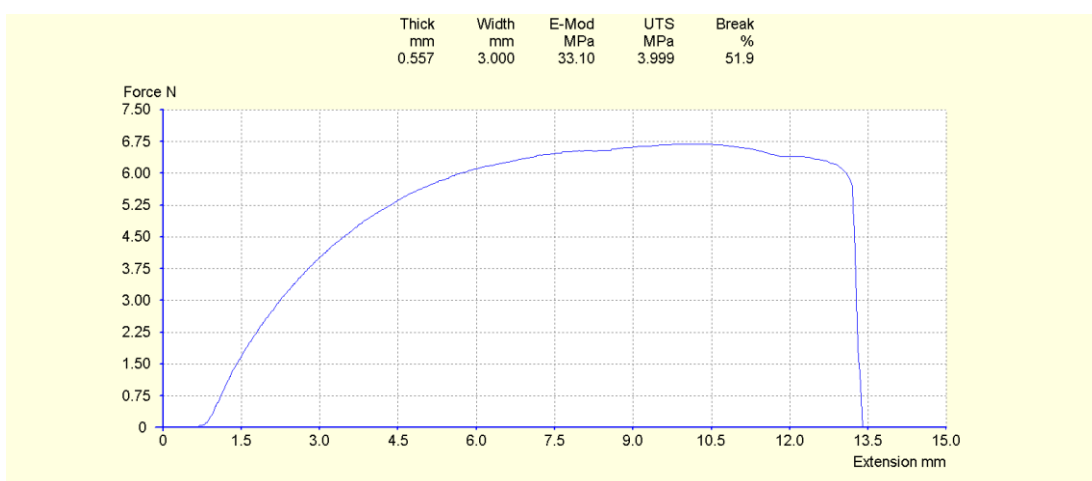
2nd for mechanical properties3rd for mechanical properties4th for mechanical properties

5th for mechanical properties



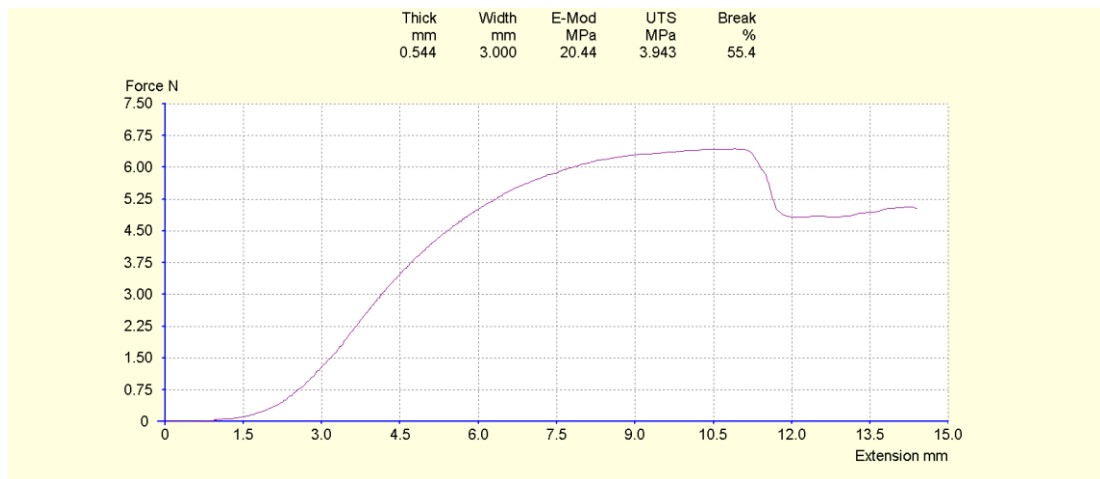
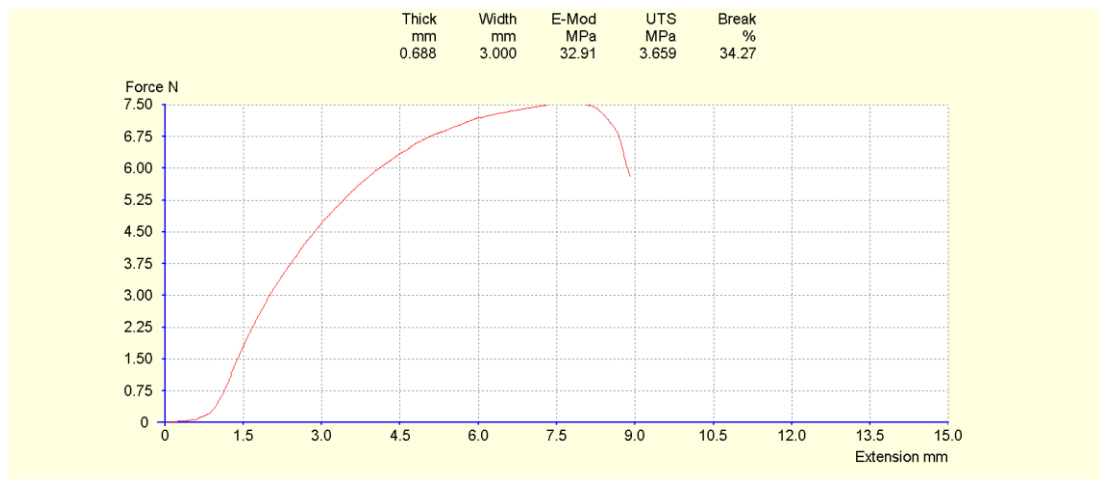
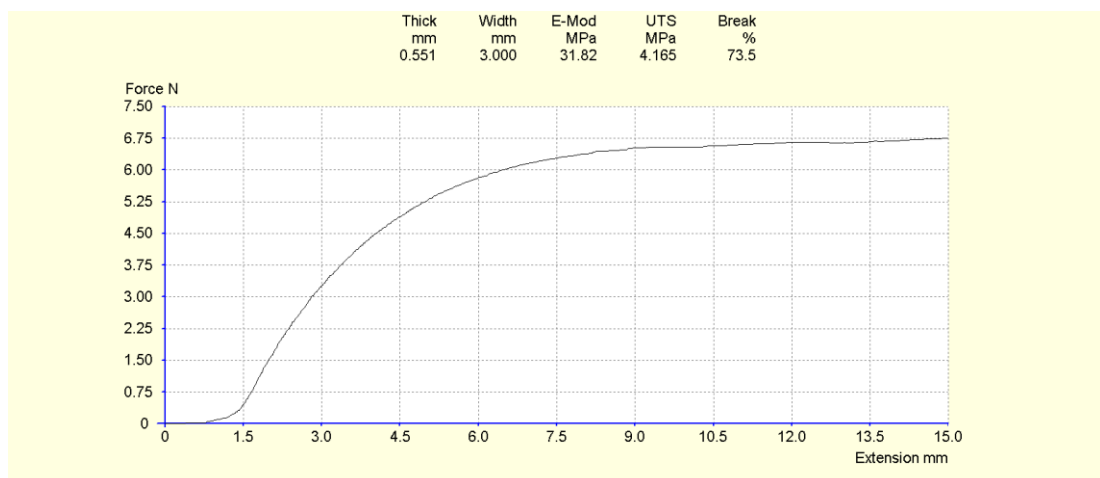
H. Mechanical properties graph for PVA/BPP blend film 2.0ml of glycerol

1st for mechanical properties



2nd for mechanical properties



3rd for mechanical properties4th for mechanical properties5th for mechanical properties

APPENDIX B: Degradation Rate for Biodegradability Test

A. Table of weightage of non-biodegradable plastic bag film and PVA/BPP blend films in 2 week duration

Dumbbell shape film	Weightage of blend film, g		
	Day-0	Day-7	Day-14
Non-biodegradable plastic bag film	0.0054	0.0054	0.0054
PVA/BPP without glycerol	0.1599	0.1524	0.1456
PVA/BPP 0.5ml glycerol	0.2653	0.2476	0.2230
PVA/BPP 1.0ml glycerol	0.2898	0.2752	0.2577
PVA/BPP 1.5ml glycerol	0.2998	0.2795	0.2532
PVA/BPP 2.0ml glycerol	0.2714	0.2562	0.2266

B. Table for degradation rate of non-biodegradable plastic bag film and PVA/BPP blend films in 2 week duration

Dumbbell shape film	Percentage of degradation, %		
	Day-0	Day-7	Day-14
Non-biodegradable plastic bag film	0.00	0.00	0.00
PVA/BPP without glycerol	0.00	4.69	4.46
PVA/BPP 0.5ml glycerol	0.00	6.67	9.94
PVA/BPP 1.0ml glycerol	0.00	5.04	6.36
PVA/BPP 1.5ml glycerol	0.00	6.77	9.41
PVA/BPP 2.0ml glycerol	0.00	5.60	11.55