

**EFFECT OF LACTIC ACID AS PLASTICIZING  
AGENT ON THE TENSILE AND  
BIODEGRADABLE PROPERTIES OF CORN COB  
POWDER/POLYVINYL ALCOHOL BLEND FILM**

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AND BIODEGRADABLE PROPERTIES OF CORN COB  
POWDER/POLYVINYL ALCOHOL BLEND FILM**

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

**Faculty of Engineering and Green Technology  
Universiti Tunku Abdul Rahman**

**June 2023**

## 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

I certify that this project report entitled “**EFFECT OF LACTIC ACID AS PLASTICIZING AGENT ON THE TENSILE AND BIODEGRADABLE PROPERTIES OF CORN COB POWDER/POLYVINYL ALCOHOL BLEND FILM** ” was prepared by **CHAI WAN QI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Petrochemical Engineering at Universiti Tunku Abdul Rahman.

Approved by,

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Supervisor :

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**ABSTRACT**

In this study, the blended film was prepared from a PVA/CCP/lactic acid blended film using the solution casting method. Blended was prepared by modifying the composition of lactic acid using the one-factor-at-a-time (OFAT) method. Attenuated total reflectance (ATR) spectroscopy was used to identify the functional group of CCP and each PVA/CCP/lactic acid blended film. Beside, thermogravimetric Analysis (TGA) was used to determine the thermal stability of CCP and each PVA/CCP/lactic acid blended films. In the others hand, the mechanical properties of each PVA/CCP/lactic acid blended film were examined using a tensile test to check their tensile strength, elongation at break and elastic modulus. According to the results, the elastic modulus and tensile strength with the highest values were 14.09 MPa and 445.7 MPa, respectively, and the elongation at break value was 15.12%. After the tensile test, the cross-sectional morphology of the PVA/CCP/lactic acid blended films with the lowest, medium and maximum tensile strengths was examined using scanning electron microscopy (SEM). In addition, a soil burial test called biodegradability test was conducted to study the biodegradability. According to the results, among all the blended films, the films containing 1.5 ml of lactic acid had the highest biodegradability.

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**LIST OF SYMBOLS/ABBREVIATIONS**

cm <sup>-1</sup>	Centimetres
kg	Kilogram
mm	Millilitres
MPa	MegaPascal
%	Weight percentage
°C	Degree Celsius (temperature unit)
ATR	Attenuated Total Reflectance Spectroscopy
CAGR	Compound annual growth rate
CCP	Corn Cob Powder
CNC	Cellulose nanocrystals
CNF	Cellulose nanofibrils
CGA	Chitosan glutaraldehyde
HDPE	High Density Polyethylenexvii
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
OPA	Oriented polyamide
OFAT	One-factor-at-a-time
PA	Polyamides
PBAT	Poly(butylene adipate-co-terephthalate)
PBS	Polybutylene succinate
PE	Polyethylene
PEF	Polyethylene Furanoate
PET	Polyethylene Terephthalate
PGA	Polyglycoluc acid
PHA	Polyhydroxyalkanoate
PHAs	Polyhydroxyalkanoates

PLA	Polyactic acid
PLAs	Polylactic acids
POME	Palm oil mill effluent
PP	Polypropylene
PTT	Polytrimethylene terephthalate
PVA	Polyvinyl Alcohol
PVC	Polyvinyl chloride
SDGs	Sustainable development goals
SEM	Scanning Electron Microscopy
SFP	Soy protein isolate
TGA	Thermogravimetric analysis
UTS	Ultimate tensile strength



## CHAPTER 1

### INTRODUCTION

#### 1.1 Background

Plastic is a material that can be molded into different shapes and forms. It is typically made from petrochemicals, which are derived from crude oil or natural gas. Plastic is made up of long chains of molecules called polymers, which give it its unique properties. These polymers are formed through a process called polymerization, where small molecules called monomers are joined together to form long chains. The first plastic, Bakelite, was invented by Leo Baekeland in 1907. (Baekeland, 1945) Bakelite is a type of thermosetting plastic, which means that once it is formed, it cannot be melted or reshaped. Bakelite was used in a wide range of products, including electrical insulation, automotive parts, and telephones.

Now a days, plastics have become one of the most widely used materials in the world. Plastics are popular due to their versatility, durability, and low cost. They can be molded into different shapes and sizes, are lightweight, and can be produced at a large scale. Plastics are used in wide range of products, including packaging, electronics, building materials, automotive parts, and medical devices. However, the use of traditional plastics has also led to some environmental concerns, as they need around hundreds of years to completely decompose and can harm wildlife and ecosystems. (British Plastics Federation, 2021) This has led to development of bioplastics, which mostly made from renewable resources, for example corn starch, sugarcane, or vegetable fats, and have a lower environmental impact compared to traditional plastics.

The concept of bioplastics dates back to the 1920s, but it was not until the 1980s that research and development began to gain momentum. (World Intellectual Property Organization, 2021) The first commercially successful bioplastic was created in 1990 by the Italian company Novamont, which developed Mater-Bi, a biodegradable plastic made from corn starch. Since then, bioplastics have gained popularity as an alternative to traditional plastics due to their lower environmental impact. Bioplastics are used in a range of products, including food packaging, consumer goods, and medical devices.(Papong et al., 2021) However, they still face some challenges, such as cost, limited availability of raw materials, and the need for proper disposal methods.

Lactic acid, also known as 2-hydroxypropanoic acid, is a carboxylic acid found naturally in many foods, including dairy, fruits, and vegetables. It is also produced in the human body during metabolism and exercise. Due to its physical and chemical properties, lactic acid has a wide range of industrial applications. Lactic acid can be produced biologically and chemically. The biological production of lactic acid by microorganisms such as lactic acid bacteria is the most widespread method. This process involves the fermentation of sugars like glucose by microorganisms, which convert the sugars into lactic acid. Lactic acid can be polymerized to produce polylactic acid (PLA), which is a biodegradable and compostable thermoplastic that has a range of applications in packaging, textiles, and medical implants. Other bioplastics that can be made from lactic acid are polyglycolic acid (PGA) and polyhydroxyalkanoates (PHA). (Abedini Najafabadi et al., 2021)

Polyvinyl alcohol (PVA) made by polymerizing vinyl acetate which was water-soluble synthetic polymer and then hydrolyzing the resulting polymer. PVA is a versatile material with a range of applications including adhesives, coatings, textiles and packaging. (Mishra & Keshri, 2018) The biodegradable properties of PVA make it a potential candidate for use in bioplastics. PVA-based bioplastics have the advantage of being made from renewable biomass sources and are biodegradable and compostable. PVA-based bioplastics can be made by blending PVA with other biodegradable polymers such as PLA or starch. The addition of lactic acid to PVA-based bioplastics can have a significant impact on their properties. In this case, lactic

acid can be added to PVA to create a cross-linked network through esterification, which improves the thermal and mechanical properties of PVA-based bioplastics. (Kumar et al., 2017)

The addition of starch, such as corn cobs, to lactic acid/PVA bioplastics can further improve their properties. The starch can act as a filler and reinforce the polymer matrix, improving the material's mechanical properties for example tensile strength and elongation at break. When starch is added to bioplastics, it can improve their biodegradability. (Nair et al., 2017) Biodegradation is a process by which microorganisms such as bacteria and fungi break down bioplastic material into smaller compounds that can be absorbed into the environment. The biodegradation of bioplastics involves the hydrolysis of ester bonds in the polymer backbone, resulting in the release of monomers that can be metabolized by microorganisms. In summary, adding starch to bioplastics can improve their biodegradability and compostability by providing a natural filler that can promote the colonization of microorganisms that can degrade the material.

## **1.2 Problem statement**

Traditional plastics are mostly made from non-renewable resources such as crude oil, and their production and use have significant negative impacts on the environment. The extraction of crude oil to make plastics has led to habitat destruction and the release of pollutants into the air, water and soil. In addition, the production process of conventional plastics consumes large amounts of energy, which contributes to greenhouse gas emissions and climate change. (Grau & Sánchez, 2010) The disposal of conventional plastics also entails ecological challenges. Many plastics end up in landfills, where they can take hundreds of years to break down, releasing harmful chemicals into the environment. Some plastics also end up in the ocean, where they harm marine life and accumulate in large floating islands of plastic waste. (Adebayo-Tayo and Adeyemo, 2019) Without the development of bioplastics, the use of traditional plastics would continue to harm the environment and deplete limited resources, leading to a potentially unsustainable future. Therefore, the

development and use of bioplastics offer a sustainable alternative to traditional plastics as they are derived from renewable resources and can biodegrade in a shorter time, reducing the negative environmental impact of plastic waste.

The need for sustainable alternatives to traditional plastics is critical to alleviating these issues. Bioplastics offer a sustainable alternative because they are made from renewable raw materials and are biodegradable. Without the development and implementation of bioplastics, the negative environmental impact of conventional plastics and the depletion of limited resources will continue to worsen, leading to a potentially unsustainable future. In this case, it was closely linked to several Sustainable Development Goals (SDGs), including SDG 12: Responsible Consumption and Production, SDG 13: Climate Action, and SDG 14: Life Below Water. SDG 12 aims to ensure sustainable consumption and production patterns by promoting the efficient use of resources, reducing waste and encouraging the development of sustainable alternatives. SDG 13 aims to combat climate change by reducing greenhouse gas emissions and promoting sustainable practices. SDG 14 aims to conserve and sustainably use the oceans, seas and marine resources by reducing marine pollution, including plastic waste. The development and use of bioplastics can help achieve these SDGs by promoting sustainable consumption and production patterns, reducing greenhouse gas emissions and reducing ocean pollution from plastic waste (Gavi, 2023).

Bioplastics have emerged as a sustainable alternative to traditional plastics that have a negative impact on the environment. Bioplastics is mostly made from renewable resources, for example plants and biomass and are biodegradable, making them environmentally friendly. Incorporation of lactic acid into bioplastics has been found to improve their mechanical properties such as tensile strength and elasticity, and enhance their biodegradability (Nair et al., 2017). Lactic acid is a natural organic acid produced by the fermentation of carbohydrates and is widely available from renewable sources such as corn and sugar cane.

The use of lactic acid in bioplastics not only improves their mechanical properties but also extends their shelf life. By incorporating renewable raw materials such as starch into bioplastics, their biodegradability can be improved and the

environmental impact reduced. In addition, bioplastics can help address the global challenge of reducing plastic waste and pollution, which poses a significant threat to the environment and human health. It is therefore essential to study the effect of lactic acid on the mechanical properties of bioplastics in order to optimize their performance and functionality (Kumar et al., 2017).

### **1.3 Aims and Objectives**

The main purpose of this research project is to synthesize, study and evaluate the biodegradable properties of polyvinyl alcohol (PVA)/corn cob powder (CCP) blended film. The sub-objectives are as follows:

- i. To characterize the polyvinyl alcohol (PVA) and corn cob powder (CCP) blended film.
- ii. To evaluate the effect of lactic acid on the mechanical properties of PVA/CCP blended film.
- iii. To evaluate the effect of lactic acid on the biodegradable properties of PVA/CCP blended film.

### **1.4 Scope of Study**

The scope of this study is focused on the synthesis, characterization, and evaluation of the biodegradable properties of PVA/CCP blended film. The study will investigate the effect of lactic acid on the mechanical and biological properties of the PVA/CCP blended film. To achieve the objectives, there were three scopes that need to be identified or perform experiment. Firstly, the blending of PVA/CCP was performed by using the solution casting method. After that, characteristics of CCP sample and PVA/CCP blended film were determined and analyzed by using fourier transform infrared spectroscopy (FTIR) which was attenuated total reflectance spectroscopy (ATR) method and thermogravimetric analysis (TGA). Next, the

composition of lactic acid in blending of PVA/CCP film by using One-factor-at-a-time (OFAT) method is one of the parameter that used in this experiment. In addition, mechanical characteristics of blended PVA/CCP film incorporate with lactic acid was determined. The mechanical characteristics are tensile strength, elongation and Young's modulus. Lastly, the biodegradable properties was analyzed by soil burial test method. The test would be carried out for one month. During the test, the weight of each blended film would be weight and record down with an interval of 1 week.

## CHAPTER 2

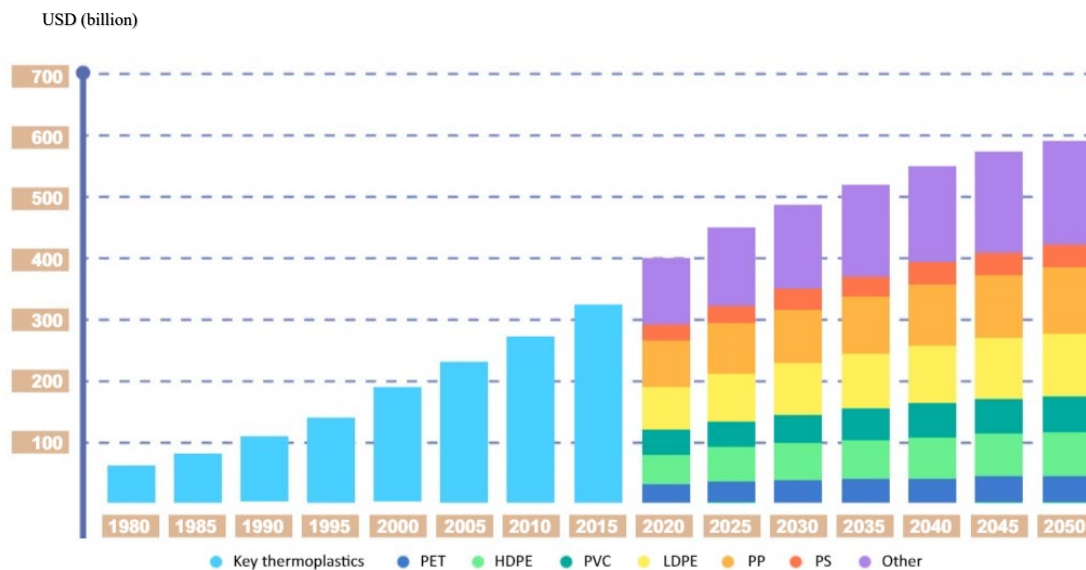
### LITERATURE REVIEW

#### 2.1 Plastic Industry in Malaysia

In the Malaysian economy, the plastics sector is very important. Like wood, paper or wool, plastic is an organic material. Natural resources such as cellulose, coal, natural gas, salt and petroleum are used to produce plastics. The plastics market in Malaysia is segmented into types, technologies and applications. The market is divided into three types: engineering plastics, bioplastics and conventional plastics (Nguyen et al,2021). By technology, the market is segmented into blow molding, extrusion, injection molding and other technologies. The market can be segmented into blow molding, extrusion, injection molding and other technology-based technologies.

According to the forecast period of 2021 to 2028, the Malaysian plastics market is predicted to exhibit a compound annual growth rate (CAGR) of 5% (Department of Environment Malaysia, 2021). The most commonly produced resin types globally include polypropylene (PP), low-density polyethylene (LDPE/LLDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), as seen in **Figure 2.1** which displays the trend of global production of key plastic resins from 1980 to 2050. The demand for flexible packaging has grown substantially as there is an increasing need for personal and healthcare products, pharmaceuticals, and packaged food and beverages. However, the long-term growth of the market may be hindered by environmental concerns regarding plastic usage. In the future, opportunities for the market may emerge from

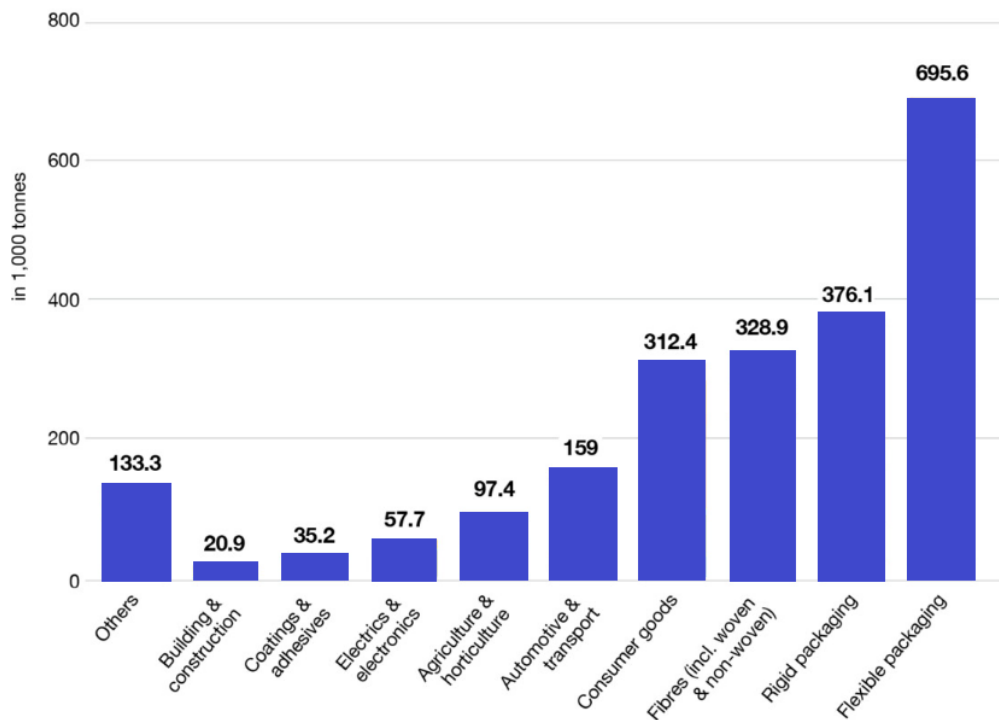
the development of the aerospace industry, increased usage of biodegradable plastics, and a stronger emphasis on recycling.



**Figure 2.1:** Global production trend on key resin (Kementerian Alam Sekitar dan Air Malaysia, 2021)

By application, the market is segmented into packaging, electrical & building electronics, construction, automotive & transportation, and other applications. **Figure 2.2** shows that the main application category of the Malaysian plastics market is packaging (European Bioplastics, 2023). Plastic packaging is preferred over other materials due to its durability, lightweight, and cost-effectiveness. It is also versatile and can be easily molded into various shapes and sizes, making it suitable for a wide range of packaging applications. Improved ease of moulding, chemical resistance and wear, puncture resistance and good mechanical strength are the main drivers behind the increasing use of plastics in the packaging sector.



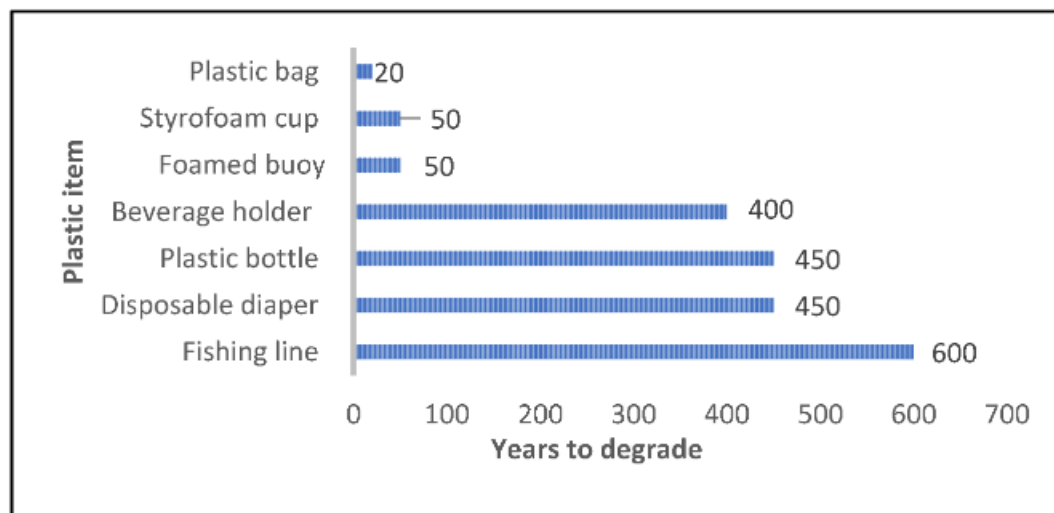


**Figure 2.2:** Market Segments for Different Plastic Product in Malaysia (European Bioplastics, 2023)

Plastic products are typically produced and reused until they reach the end of their lifespan, at which point they become waste. At this stage, there are two main options land filling, which often leads to plastic waste escaping into the environment, or recovery through incineration or recycling for energy and resources. Land filling is a common solid waste management method used by most countries worldwide, involving the disposal of waste in burial sites. In contrast, waste recovery involves recycling plastic waste to create secondary raw materials. According to UNEP statistics, only 21% of plastic waste is recovered, with 12% and 9% being incinerated and recycled, respectively (Harikrishnan et al, 2021). The remaining plastic waste is disposed of in landfills.

### 2.1.1 Plastic Pollution

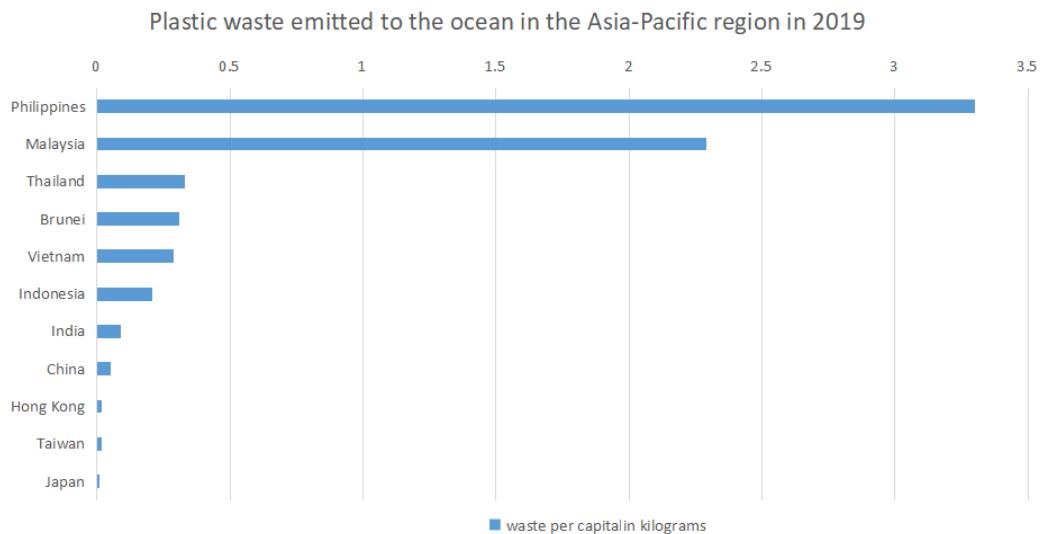
Plastic products have become ubiquitous in modern society, but their stability makes them a persistent pollutant. In fact, it is estimated that around 1.6 million barrels of oil are used each year solely for producing plastic bottled water (Kim, J., & Kim, Y., 2020). Unfortunately, plastic waste is one of the many types of waste that takes an extremely long time to decompose. Typically, plastic items require up to 1000 years to break down in landfills, with plastic bags taking between 10-20 years, and plastic bottles needing 450 years as shown in the **Figure 2.3**. Even after they decompose, micro-plastics are formed, which can be ingested by marine animals and end up on our plates in the form of seafood, as well as in table salt and water.



**Figure 2.3:** Plastic degradation timeline (Kim, J., & Kim, Y., 2020)

A large portion of plastic waste ends up in the ocean due to inadequate disposal methods, such as littering or land filling without proper safeguards. It's difficult to fathom the amount of plastic waste we produce and discard on a daily basis. Plastic bottles and caps account for roughly one-third of all plastic waste, while another third is composed of plastic bags and food wrappers. The remaining waste mainly consists of food-related items such as lids, straws, cups, and utensils. Based on **Figure 2.4**, the Philippines released the highest amount of plastic waste per capital into the ocean among Asia-Pacific region in 2019, with Malaysia following closely behind (Statista, 2021). Additionally, submicroscopic particles of plastic can be inhaled when they float in the air like dust. This size reduction is sometimes

intentional, as with micro-plastics added to cosmetics and toothpaste. Even when intended to be washed into wastewater, these particles still find their way into drinking water supplies around the world.



**Figure 2.4:** Plastic waste emitted to the ocean per capita in the Asia-Pacific region in 2019 (Statista, 2021)

Plastic pollution in the ocean poses a serious threat to the wildlife that inhabits it. The impact of plastic debris on marine animals is severe and often fatal. Marine animals, such as sea turtles, seabirds, whales, dolphins, and other marine mammals, often mistake plastic debris for food and ingest it (Biological Diversity, 2023). This can lead to serious health issues, starvation, and death. For example, sea turtles, which are one of the most commonly affected marine animals, often mistake plastic bags for jellyfish, their primary food source. Once ingested, the plastic bags block the digestive tract of the turtle, leading to starvation and eventually death. It is estimated that around 52% of sea turtles have ingested plastic debris at some point in their life, with many dying as a result (World Wildlife Fund Australia, 2023). Seabirds are also greatly affected by plastic pollution in the ocean. They mistake plastic pellets for fish eggs and feed them to their chicks, causing malnutrition and death. In fact, it is estimated that around 90% of all seabirds have ingested plastic debris, with many dying as a result. Plastic pollution in the ocean has a devastating impact on marine ecosystems and the wildlife that inhabits them.

## **2.2 Types of Plastics**

There was two types of plastic, which was traditional petroleum-based plastic and the biodegradable plastic.

### **2.2.1 Traditional Petroleum-based Plastics**

Petroleum-based plastics, as the name suggests, are derived from petroleum, a non-renewable fossil fuel. These plastics are used in many everyday products, including food packaging, disposable utensils and electronic devices (Syafiuddin et al, 2020). However, the production process of these plastics involves the extraction and refining of oil, resulting in significant environmental damage. The process of extracting and refining oil causes air and water pollution and can lead to habitat destruction and land degradation.

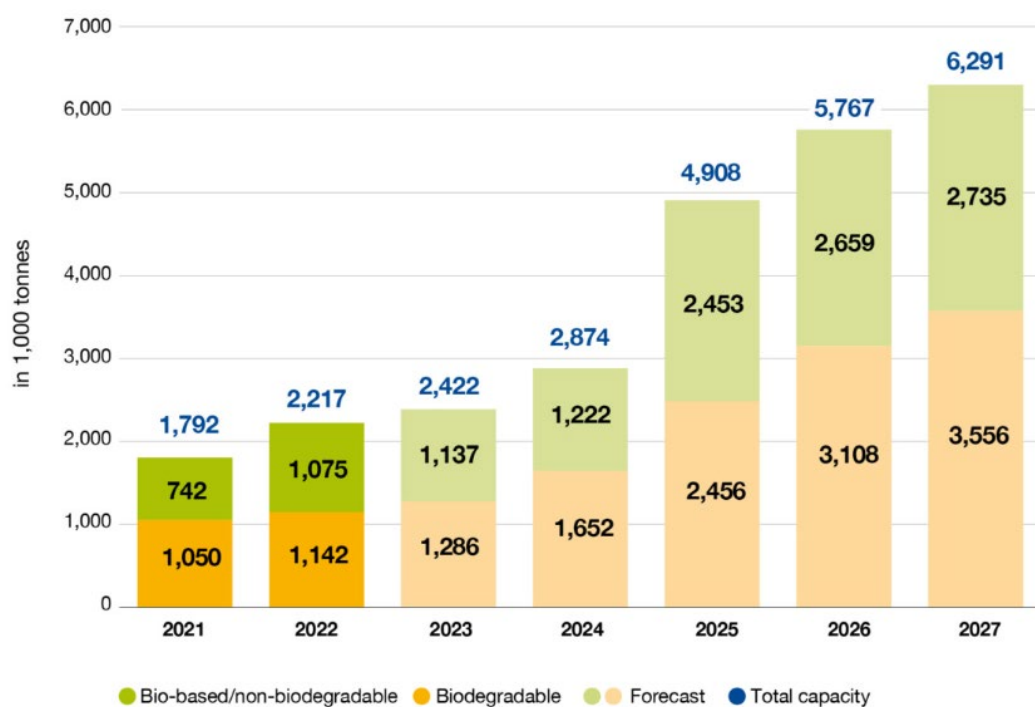
Another major problem with petroleum-based plastics is their non-biodegradable nature. Once disposed of, they do not naturally degrade and can remain in the environment for hundreds or even thousands of years (Kim, J., & Kim, Y, 2020). This has led to the accumulation of plastic waste in oceans, lakes and other natural areas, which can have serious impacts on wildlife and ecosystems. In addition, burning petroleum-based plastics releases harmful pollutants into the air that contribute to air pollution and climate change.

Because of these concerns, there is growing global awareness of the need to reduce the use of petroleum-based plastics. Initiatives to promote recycling, the use of biodegradable alternatives and the development of sustainable production processes using renewable materials are gaining momentum. The aim is to minimize the environmental damage caused by petroleum-based plastics and to create a more sustainable and environmentally friendly approach to the production and use of plastics (Syafiuddin et al, 2020).

### 2.2.2 Biodegradable Plastic

Biodegradable plastic is designed to degrade naturally over time, unlike traditional petroleum-based plastics. It is made from natural materials, for example corn starch, sugar cane or potato starch, which are biodegradable. This type of plastic can be broken down by microorganisms such as bacteria, fungi and algae. These types of plastics are commonly used in various products, including food packaging, disposable utensils, and bags (Nguyen et al, 2021).

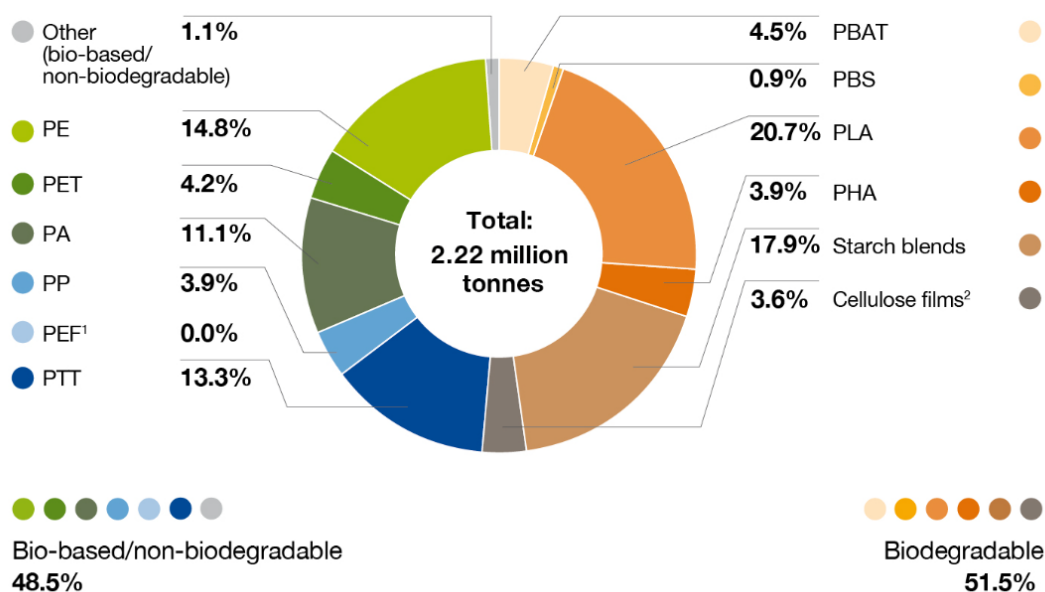
When properly disposed of in composting facilities, biodegradable plastics can decompose within months to years, depending on the material and conditions. This process helps reduce amount of plastic waste which ends up in landfills and contributes to pollution. Besides, biodegradable plastics can be a more sustainable option than traditional petroleum-based plastics because they are made from renewable resources and reduce our dependence on fossil fuels. At present, more than half of the global bioplastics production capacities, which include various types of biodegradable plastics such as PLA, PHA, and starch blends, exceed 1.1 million tonnes (European Bioplastics, 2023). This **Figure 2.5** is expected to surge to over 3.5 million by 2027, mainly due to advancements in polymer technology, particularly in the production of polylactic acids (PLAs) and polyhydroxyalkanoates (PHAs).



**Figure 2.5:** Global Production Capacities of Bioplastics (European Bioplastics, 2023)

On the other hand, bio-based, non-biodegradable plastics, which include bio-based polyethylene (PE), polyethylene terephthalate (PET), and polyamides (PA), make up around 49 percent of the global bioplastics production capacities at almost 1.1 million tonnes as shown in **Figure 2.6** (European Bioplastics, 2023). However, the widespread use of biodegradable plastics presents certain problems. They can be more expensive to produce than petroleum-based plastics and under certain conditions, such as marine environments, landfills or marine environments, are not easily degraded. In addition, during the decomposition process, biodegradable plastics can release methane, a powerful greenhouse gas that contributes to climate change.

**Global production capacities of bioplastics 2022**  
(by material type)



**Figure 2.6:** Global Production Capacities of Bioplastics 2020 (European Bioplastics, 2023)

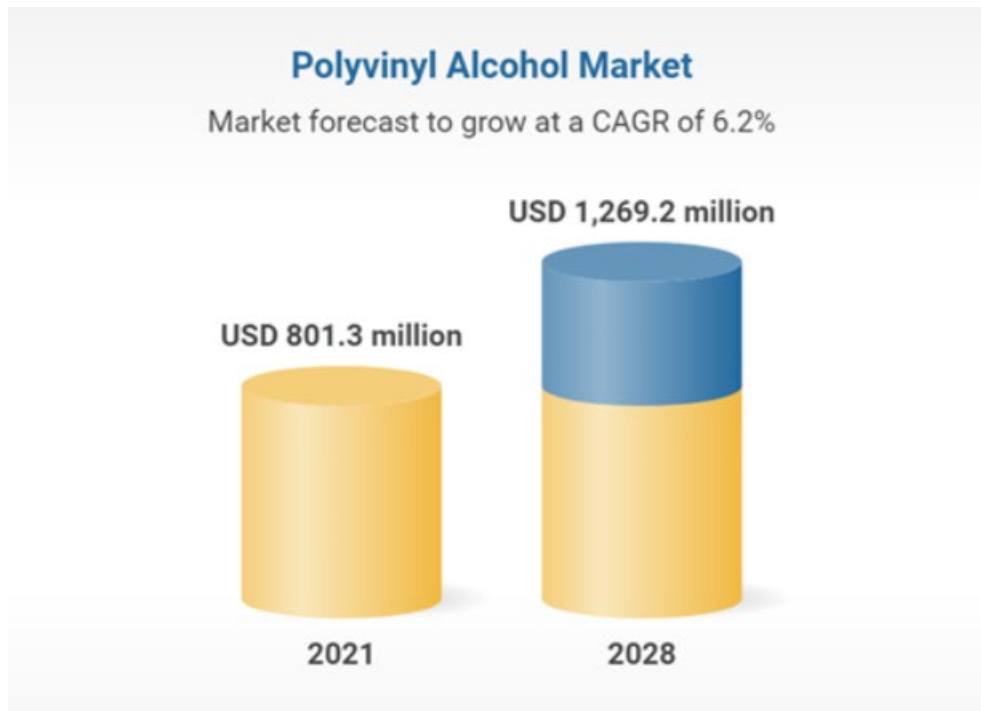
Efforts are being made to improve the production and use of biodegradable plastics and to find sustainable alternatives to traditional plastics. This includes the development of new materials, innovative recycling and waste management practices,

and educating consumers about proper disposal and recycling methods to reduce plastic pollution.

### **2.3 Polyvinyl alcohol (PVA)**

PVA is a water-soluble polymer with a variety of applications in various industries due to its unique properties such as high tensile strength, excellent barrier properties, and biodegradability. In this reason, PVA plays a significant role in various industries such as the packaging industry, construction industry, textile industry, pharmaceutical industry, adhesive industry, agriculture industry, and many other industries.

For the projection period from 2021 to 2028, the market size of PVA is expected to grow at a CAGR of 6.2% as portrayed in **Figure 2.7** Emergen Research's PVA study provides an analysis and overview of the numerous elements that are anticipated to be present during the estimated period along with their impact on the market growth (Emergen Research, 2021). The PVA market is expected to grow in response to the growing demand for bio-based PVA products. Accordingly, the rapid increase in the use of packaging in the food industry and the increase in material consumption in the construction industry are both expected to be major drivers for the growth of the PVA market, over the forecast period of 2021 to 2028 (Research and Markets, 2021). The rapid industrialization and increase in innovation in the packaging sector should also have a positive impact on the expansion of the PVA market.



**Figure 2.7:** Global Polyvinyl Alcohol Market, 2021-2028 (Research and Markets, 2021)

### 2.3.1 Polyvinyl Alcohol (PVA) Blended Film

PVA blended film is a type of film made by blending PVA with other materials to create a composite material with enhanced properties.

#### 2.3.1.1 PVA/Starch Blend Film

PVA/Starch Blend Film is a kind of biodegradable plastic film made by combining PVA and starch. PVA is a synthetic polymer that can dissolve in water, while starch is a natural polymer that can be obtained from sources such as corn, potatoes, or tapioca. The blended of PVA and starch creates a material that is both biodegradable and water soluble. This makes it a viable alternative to traditional petroleum-based plastics for applications such as food packaging, disposable bags,



and other single-use products (Mhaisalkar, Gadekar, and Kadam, 2022). When properly disposed of, the PVA/starch blended film can naturally degrade in the environment without leaving any harmful residues. However, the widespread use of the PVA/starch blended film presents some challenges. It can be more expensive to manufacture than traditional plastics, and its properties such as strength and flexibility may not be suitable for all applications. In addition, its biodegradability and water solubility can also make it less durable and more prone to damage during shipping and storage.

#### **2.3.1.2 PVA/Glutaraldehyde Blend Film**

PVA/CGA blended film is a biodegradable plastic film made from a blend of PVA and chitosan glutaraldehyde (CGA). PVA is a water-soluble synthetic polymer while CGA is a natural polymer derived from chitin found in the exoskeletons of crustaceans. CGA is used to cross link PVA and improve its mechanical properties. The resulting PVA/CGA blended film has good biodegradability, bio-compatibility, and mechanical strength, making it a promising material for various applications (Liu et al, 2021) It is widely used in the food industry as a packaging material for fresh produce because it is non-toxic and can help extend food shelf life. Films made from PVA/CGA blends can also be used in biomedical applications such as wound dressings and drug delivery systems due to their bio-compatibility and biodegradability.

#### **2.3.1.3 PVA/Nano-Soy Protein Isolate Blend Film**

PVA/Nano-SFP blended film is a type of biodegradable film made by blending PVA with nanoparticles of starch and soy protein isolate (SFP). The addition of nanoparticles to the PVA matrix improves the mechanical and barrier properties of the resulting film (Science.gov, 2023). The nanoscale dimensions of the particles create a more uniform distribution within the film, which enhances its structural

integrity and reduces the risk of cracking or tearing. Additionally, the presence of nanoparticles increases the water resistance and oxygen barrier properties of the film, which makes it suitable for use in food packaging and other applications where moisture and air exposure must be minimized. Overall, PVA/nano-SFP blended films have potential as an environmentally friendly alternative to traditional petroleum-based plastics.

#### **2.3.1.4 Oriented Polyamide/PVA Blend Film**

OPA/PVA blended film is a type of polymer film that is produced by blending together two different types of polymers which was oriented polyamide (OPA) and PVA. This blended results in a film that has improved mechanical properties and barrier properties compared to each individual polymer (Nurul et al, 2019) OPA is a type of nylon polymer that is known for its strength and durability, while PVA is a water-soluble polymer that is often used in packaging materials due to its excellent barrier properties against gases and moisture. The resulting OPA/PVA blended film can be used in a variety of applications, including food packaging and medical packaging, due to its excellent barrier properties and high tensile strength.

## **2.4 Agricultural Waste**

Agricultural waste refers to any waste material that is generated as a byproduct of agricultural activities. This can include waste from crop production, livestock farming, and other agricultural practices. Agricultural waste can be organic or inorganic in nature, and can include materials such as crop residues, animal manure, food waste, and plastics used in farming (Ogodo et al, 2017) Besides, agricultural waste can have negative impacts on the environment if not properly managed and disposed of. For example, improperly disposed animal waste can contaminate water sources and cause environmental pollution, while plastic waste can take hundreds of years to decompose and contribute to landfill and marine pollution. However,

agricultural waste can also be recycled, reused, or converted into useful products such as compost, bio-fuels, and animal feed, which can help reduce waste and support sustainable agricultural practices.

#### **2.4.1 Corn Cob Waste**

Corn cob trimmings refer to the outer husk, or woody part, of the corn cob that remains after the kernels have been harvested for food or other uses. Corn cobs are generally made up of cellulose, hemicellulose, and lignin, all of which are complex organic compounds (NewINTI, 2023). The use of corn cobs as waste as shown in **Figure 2.8** has become an important area of research because they provide a readily available source of biomass that can be used to produce bio-fuels, chemicals, and other value-added products (My Frugal Home, 2023). Using corn cobs as a feed stock for bio-fuel production can help reduce reliance on fossil fuels, which are non-renewable and contribute to climate change. Additionally, corn cobs are used in various agricultural applications such as animal bedding and as a soil conditioner to improve soil quality and water retention. They can also be used as an energy source for cooking and heating in rural areas. However, improper disposal or accumulation of corncob waste can cause environmental damage (NewINTI, 2023). For example, if corncob waste is not properly disposed of, it can decompose and release greenhouse gases, contributing to air pollution and climate change. It can also leach nutrients and organic matter in soil and water, affecting local ecosystems and water quality.



**Figure 2.8:** Picture of Corn Cob Waste (My Frugal Home, 2023)

#### 2.4.2 Banana Peel Waste

Banana peel waste as shown in **Figure 2.9** is the outer covering of discarded bananas that results from banana consumption and processing. Bananas are one of the most consumed fruits in the world with an estimated production of around 119.83 million tonnes worldwide, or about 16% of total fruit production (Chow, 2022). However, the bulk consumption of bananas also results in a significant amount of waste, with banana peels accounting for around 30-40% of the fruit's total weight. This equates to approximately 3.5 million tons of banana peel waste generated each year (Chow, 2022). Banana peel waste is often considered organic waste and is usually dumped in landfills or decomposed in open environments. However, the slow decomposition process of banana peels, which can take up to two years, and the release of greenhouse gases (GHGs) during decomposition, including methane, contribute to environmental concerns (Fresh Fruit Portal, 2014). Methane is a powerful greenhouse gas that has a significantly higher global warming potential than carbon dioxide and thus contributes to climate change. Although banana peels are considered waste, they have the potential for various beneficial uses. One of the

beneficial uses was banana peels contain bio-active compounds that have potential applications in the pharmaceutical, cosmetic, and textile industries. Banana peel extracts have been studied for their antioxidant, antimicrobial, and anti-inflammatory properties, among other things.



**Figure 2.9:** Picture of Banana Waste (Fresh Fruit Portal, 2014)

### **2.4.3 Wood Waste**

Wood waste refers to any discarded or unused wood material generated during the various stages of wood processing, manufacturing, construction and demolition (Wood Industry, 2021). Wood waste can come in a variety of forms, including sawdust, wood chips, bark, branches, lumber, pallets, plywood and other wood-based materials that are no longer needed or used. Wood waste is an important part of solid waste streams in many countries and its disposal can pose environmental problems (Shrestha et al, 2021). When wood waste goes to landfill, it can take up valuable space, decompose to release methane, a potent greenhouse gas, and contribute to environmental pollution. However, wood waste also has the potential for various beneficial uses including biomass for energy production, wood-based products, mulching and composting.



**Figure 2.10:** Picture of Wood Waste (Wood Industry, 2021)

#### **2.4.4 Oil Palm Waste**

Malaysia plays a key role in global palm oil production and export. However, the upstream and downstream segments of the palm oil sector generate significant amounts of waste. In 2015, Malaysia's palm oil sector generated about 76 million tons of solid biomass waste, while palm oil mill effluent (POME) generated 65 million tons of waste (Ghaffarianhosein and al., 2017). According to forecasts, the production of POME biomass waste and palm oil could reach 70 to 110 million tons per year by 2020. In terms of waste management as well as solid biomass and POME greenhouse gases, the growing trend of waste generation represents significant environmental sustainability. . Concerns The disposal of palm oil waste is essential for the sustainable development of the industry and environmental protection (MPOCC, 2018). The term “oil palm waste” refers to solid biomass waste (fruit clusters, empty fruit clusters, peels, fibers and liquid wastewater) generated from palm oil production.





**Figure 2.11:** Picture of Oil Palm Waste (MPOCC, 2018)

## **2.5 Additives**

Some of the additives such as plasticizer will added into plastic to improve the properties such as flexibility, thermal stability and biodegradability.

### **2.5.1 Plasticizer**

Plasticizer are chemical additives that are added to polymers such as plastics and rubber during manufacture to change their properties. They reduce intermolecular forces between polymer chains, resulting in increased polymer flexibility, durability and processability. Plasticizer possess properties such as flexibility, low volatility, compatibility, thermal stability, and chemical resistance. They are used in a variety of applications including softening plastics such as PVC, improving processability in manufacturing techniques such as extrusion and injection molding, improving durability for outdoor applications, modifying specific properties such as electrical conductivity and flame resistance, and improving adhesives and adhesives

Coatings Flexibility. and liability. Plasticizer play a critical role in the polymer industry, contributing to the performance, processability and versatility of polymers used in various industries.

### **2.5.1.1 Glycerol**

Glycerol, also called glycerin or glycerin, is a trihydroxy alcohol that has many uses in the field of polymer chemistry (World of Chemicals, 2023). It is a colorless, odorless, and viscous liquid commonly derived from vegetable oils or animal fats through a process called hydrolysis or transesterification. One of the main uses of glycerol in polymers is as a plasticizer. Plasticizer are added to polymers to increase their flexibility, reduce their brittleness, and improve their processability. Glycerin is an effective plasticizer for various polymers, including PVC, PET, and cellulose polymers. It helps lower the glass transition temperature of polymers, making them softer and easier to process while improving their mechanical properties such as impact strength and tensile strength. In addition, glycerin can also be used as a monomer in the production of biodegradable polymers (The Kid Should See This, 2023). Through polymerization reactions, glycerin can be incorporated into polymer chains to form polyesters or polyurethanes. These biodegradable polymers find applications in areas such as packaging, agriculture, and biomedical materials where environmental sustainability and bio-compatibility are important factors.

### **2.5.1.2 Sorbitol**

Sorbitol is a commonly used sugar alcohol in the field of polymer chemistry due to its unique properties. It is a water-soluble, white, crystalline powder with a sweet taste, making it suitable for a wide range of polymer applications (Sultana et al, 2016). One of the main uses of sorbitol in polymers is as a plasticizer. Similar to glycerin, sorbitol can be added to polymers to increase their flexibility and reduce their brittleness. It acts as a plasticizer by reducing the inter-molecular forces between



the polymer chains, allowing them to move more easily and giving the material greater flexibility. Sorbitol is commonly used as a plasticizer in PVC and other polymers, where it improves their processability and improves their mechanical properties (Sultana et al, 2016). In addition, sorbitol can also be used as a monomer in the synthesis of biodegradable polymers. Through polymerization reactions, sorbitol can be incorporated into polymer chains to form polyesters or other types of polymers. These biodegradable polymers are used in applications such as packaging, agricultural films, and medical devices where environmental sustainability and bio-compatibility are important considerations.

### **2.5.1.3 Lactic Acid**

Lactic acid is a versatile organic compound that is widely used in the field of polymer chemistry. It is a colorless liquid or white crystalline solid with an acidic taste and is classified as an alpha hydroxy acid (Mishra and Khamparia, 2021). Lactic acid can be produced through the fermentation of carbohydrates by various microorganisms and can also be synthesized chemically.

One of the main uses of lactic acid in polymers is as a monomer to produce PLA, a biodegradable and bio-compatible polymer (Rosa et al, 2021). PLA is a versatile polymer that can be formed into various forms such as films, fibers and molded parts, making it suitable for a wide range of applications including packaging, agricultural films, medical implants and disposable products. PLA has attracted a lot of attention as an eco-friendly alternative to traditional fossil fuel-derived plastics because it is made from renewable resources and has a lower carbon footprint.

Lactic acid can also be used as a cross linking agent, a substance added to polymers to improve their flexibility, durability, and processability. As a cross linking agent, lactic acid can lower the glass transition temperature of polymers, making them more flexible and easier to process (Yang et al, 2020). In addition, lactic acid can improve the biodegradability and bio-compatibility of polymers, making them suitable for applications where sustainability and environmental friendliness are

important factors. In addition, lactic acid can be used in polymerization reactions to form cross-linked polymers that have improved mechanical properties and thermal stability (Yang et al, 2020). Cross-linked polymers find applications in a variety of areas, including coatings, adhesives, and biomedical materials.

## **2.6 Combination of PVA with Natural Fibre**

The combination of PVA with natural fibers has attracted increasing attention in recent years due to its potential to create durable and environmentally friendly composite materials with improved properties.

### **2.6.1 Natural Fibre Reinforced PVA Based Composite**

Natural fiber reinforced PVA composites are composite materials that combine PVA, a synthetic polymer, with natural fibers to create a durable and environmentally friendly material with enhanced properties (Ronda et al, 2015). Natural fibers used in these composites can include jute, sisal, hemp, coir, flax, bamboo and other plant fibers that are made from renewable resources and are biodegradable.

In these composites, the PVA acts as the matrix or binder, while the natural fibers provide the reinforcement. Natural fibers are usually embedded in the PVA matrix, forming a cohesive structure that improves the mechanical, thermal and barrier properties of the composite (Kalia et al, 2015) Incorporating natural fibers into PVA-based composites can enhance the material's tensile strength, flexural strength, impact resistance and other mechanical properties. Natural fibers also offer advantages such as low cost, low density, and good thermal and acoustic insulation properties that can make composites suitable for various applications.

One of the main uses of natural fiber reinforced PVA composites is in the automotive industry, where they can be used for interior parts such as door panels and dashboards to reduce weight and improve durability (Ronda et al, 2015). These composites are also used in packaging materials such as food packaging and disposable packaging, where natural fibers can improve the mechanical strength and barrier properties of PVA films. Additionally, natural fiber reinforced PVA composites have been used in building materials such as roofing membranes, panels and sheets, where they can offer improved mechanical properties and reduced environmental impact.

### **2.6.2 PVA incorporated with Various Type of Cellulose**

PVA, which incorporates various types of cellulose, is a type of composite material that combines the properties of PVA, a water-soluble synthetic polymer, with cellulose, a natural polymer found in plant cell walls (Ronda et al, 2015). The incorporation of cellulose into PVA can yield composite films with improved properties such as mechanical strength, improved thermal stability, barrier properties, and biodegradability.

Cellulose is a bio-polymer available from numerous natural sources such as wood, cotton, bamboo and other plant materials. Cellulose can be extracted and converted into various forms, including cellulose fibers, cellulose nanocrystals (CNC), and cellulose nanofibers (CNF), which can be used as reinforcements in PVA composites (Mhd Haniffa et al, 2018). The incorporation of cellulose into PVA can be accomplished by various methods such as solution casting, melt blending, electrospinning, and other techniques. The type and form of cellulose used, as well as the processing conditions, can affect the properties of the resulting PVA/cellulose composite films.

Cellulose-incorporated PVA offers multiple vaiguille in various applications (Ronda et al, 2015). For example, PVA/cellulose composite films are used in packaging materials due to their improved barrier properties against moisture, oxygen

and other gases. They are also used in food packaging due to their biodegradability and shelf life. PVA/cellulose films are used in the pharmaceutical and biomedical fields for drug delivery systems, wound dressings and tissue engineering due to their bio-compatibility and controlled release properties (Ronda et al, 2015). In addition, PVA/cellulose composite films find application in the textile industry, where they can improve the mechanical properties and performance of fabrics. They are also used in paper coatings, membranes and other specialty applications where their properties are Vaiguille.

The combination of PVA with different types of cellulose offers a versatile and environmentally friendly approach to developing composite films with improved properties for a wide range of applications. Using cellulose as a natural reinforcement in PVA films can offer improved performance, durability and a potential for biodegradability, making them attractive to various industries and applications.

## **2.7 Synthesis of Polyvinyl Alcohol Film**

The synthesis of PVA film typically involves several steps, including the preparation of a PVA solution, casting or coating of the solution onto a substrate, and subsequent drying or cross-linking to form a solid film.

### **2.7.1 Solution Casting Method**

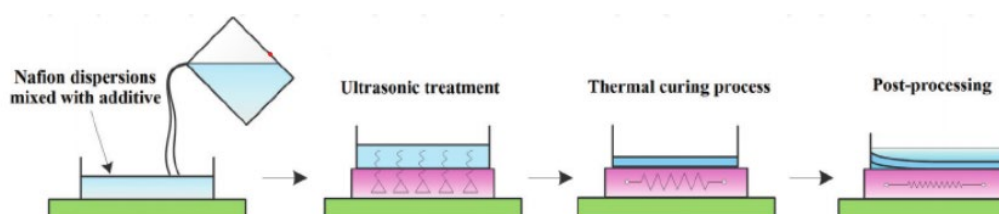
Solution casting is a widely used process for the production of polymeric films, including those based on PVA. PVA is a water-soluble synthetic polymer known for its excellent film-forming properties and wide range of applications. In the solution casting process, the polymer is dissolved in a suitable solvent to form a homogeneous solution (Lee et al, 2018). The solvent must be able to completely dissolve the polymer for a uniform solution. The concentration of the polymer in the solvent can

be adjusted to control the properties of the resulting film, such as its thickness, transparency, and mechanical properties.

Once the polymer is fully dissolved, the solution is cast onto a suitable substrate such as glass or metal using methods such as a casting knife or doctor blade to achieve the desired film thickness (Lee et al, 2018). After casting, the film is allowed to dry or undergo further post-processing steps to remove the solvent and solidify the film. Drying can be accomplished by methods such as air drying or oven drying, depending on the solvent used and the film properties desired.

The properties of solution cast PVA film can be controlled by adjusting various parameters during the casting process such as polymer concentration, solvent selection, casting method and drying or post-curing conditions as shown in **Figure 2.12** (Lee et al, 2018). The resulting film can have a wide range of properties such as transparency, flexibility, tensile strength and barrier properties depending on the specific application requirements. In addition, post-processing steps such as surface modification or coating with other materials can further improve film properties or achieve specific functionalities.

In summary, solution casting is a popular process for making PVA films, in which the polymer is dissolved in a suitable solvent, cast onto a substrate and allowed to dry or undergo post-processing steps to form a solid film. The properties of the resulting film can be tailored by adjusting various parameters during the casting process, making it a versatile technique for manufacturing PVA films.



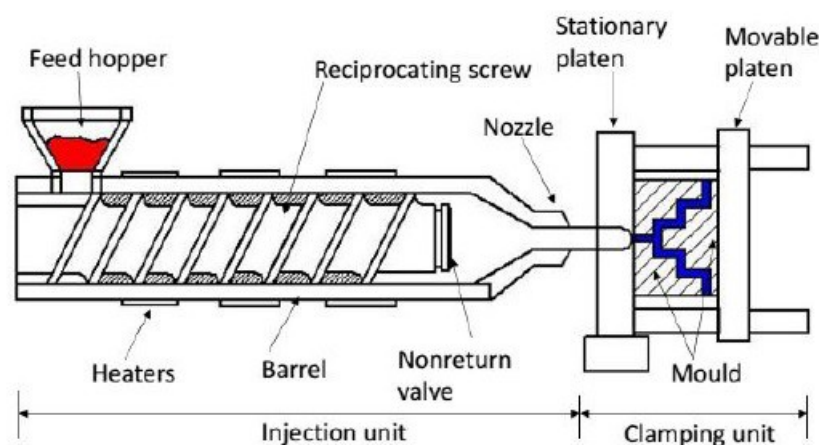
**Figure 2.12:** Solution casting procedure (Lee et al, 2018)

## 2.7.2 Injection Moulding

Injection molding is a widely used manufacturing process for producing plastic parts in large volumes. It involves injecting molten plastic material into a mold cavity under high pressure, where it cools and solidifies to form the desired shape (TWI Ltd, 2023). Injection molding is commonly used for producing complex, three-dimensional parts with high precision and repeatability.

The injection molding process begins with the plastic material as shown in **Figure 2.13**, typically in the form of small pellets, being fed into a heated barrel where it is melted by the rotation of a screw (LearnMech, 2023). The molten plastic is then injected into a mold cavity through a nozzle and runner system under high pressure. The mold cavity is typically made of two halves that are clamped together, forming a closed system. Once the plastic has filled the mold cavity and cooled sufficiently, the mold is opened, and the solidified part is ejected from the mold using ejector pins or other mechanisms.

Injection molding offers several advantages, including high production efficiency, ability to produce complex geometries, excellent part reproducibility, and cost-effectiveness for large-scale production (TWI Ltd, 2023). It is used in a wide range of industries, including automotive, consumer goods, packaging, medical, and electronics, to produce a wide variety of plastic parts, from small components to large enclosures.



**Figure 2.13:** Injection Molding (TWI Ltd, 2023)

## 2.8 Mechanical Properties of PVA Blend Film

PVA blended films exhibit a range of mechanical properties depending on the specific formulation, processing conditions, and presence of other materials in the blended.

### 2.8.1 Tensile Strength

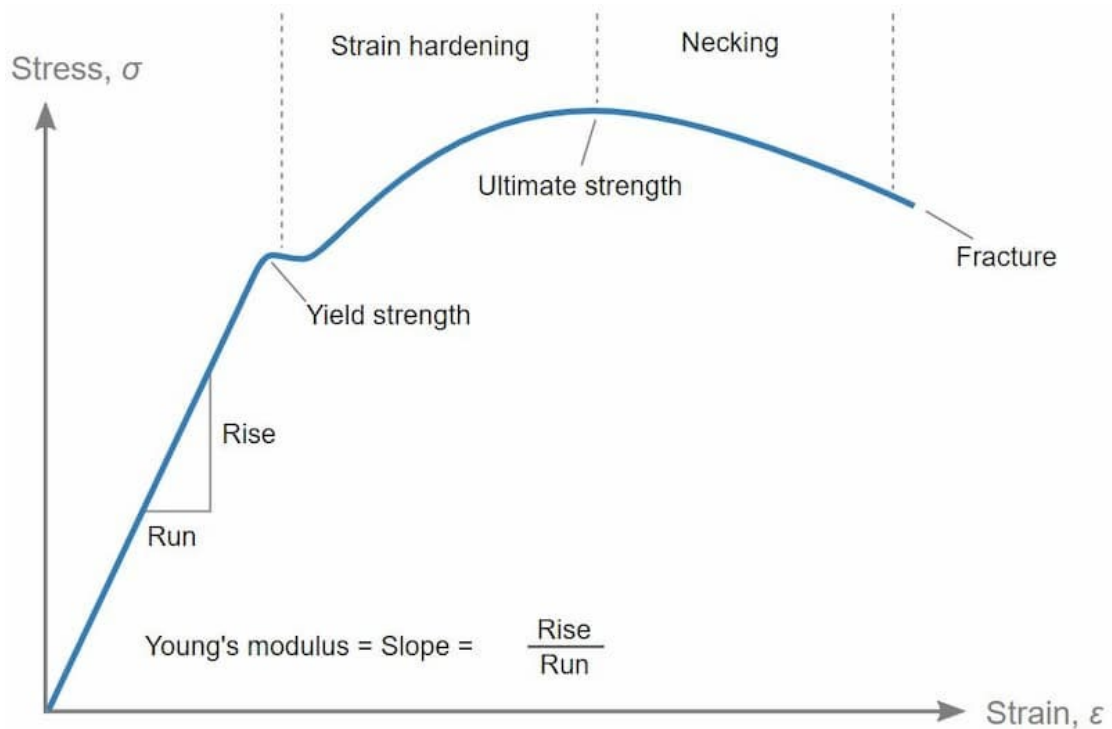
Tensile strength is a mechanical property that measures the maximum stress that a material can withstand before breaking under tensile force. It is an important parameter for evaluating the performance and durability of materials, including polymers such as PVA blended films. Tensile stress which can calculate by using **equation 2.1** which is the force needed to break film per cross-sectional area (PhysicsNet, 2023).

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

In the context of PVA blended films, tensile strength can be affected by a variety of factors, including the concentration of PVA in the blended, the presence of other polymers or additives, and processing conditions. In general, higher PVA concentrations in the blend can result in higher tensile strength as PVA is known for its good tensile properties (Jain, R., and Tandon, R, 2017). However, the addition of other polymers or additives can also affect the tensile strength of PVA blended films, and the optimal blend composition may depend on specific application requirements.

Ultimate tensile strength (UTS) is a mechanical property that represents the maximum stress that a material can withstand before breaking under tensile (strain)

forces (The Gund Company, 2021). It is usually obtained from a stress-strain curve, which is a graphical representation of the material's response to the stress applied during a tensile test.



**Figure 2.14:** Graph of Young's Modulus stress-strain curve (Fractory, 2023)

In a stress-strain curve as shown in **Figure 2.14**, stress is plotted on the y-axis and strain on the x-axis. The curve usually has several distinct areas (Fractory, 2023). Initially, the material undergoes elastic deformation, where stress and strain are linearly proportional and the material is allowed to return to its original shape after the applied stress is removed. This is represented by the linearly elastic region of the curve. As the stress increases, the material may begin to exhibit plastic deformation, with the stress increasing without a corresponding increase in strain. This is called the yield point or elastic limit, which marks the transition from elastic deformation to plastic deformation. The UTS is the highest point on the stress-strain curve and represents the maximum load that the material can withstand before failure (The Gund Company, 2021). At UTS, the material reaches its maximum strength and begins to experience necking, where localized areas of the material shrink and elongate.



Eventually, the material fractures and fragments, causing a rapid drop in stress and strain, marking the material's point of failure.

UTS is an important parameter to characterize the mechanical strength and durability of a material, including polymers. It provides information on the material's ability to withstand applied loads and is widely used in engineering and materials science to evaluate the performance of materials in various applications such as structural components, packaging materials and foils.

### **2.8.2 Elongation at Break**

Elongation at break, also known as elongation at failure or simply elongation, is a measure of a material's ability to stretch or deform before it breaks under tensile (stretching) forces (Polyglobal, 2022). Elongation at break is usually expressed as a percentage and is calculated as the change in length of the material at the point of failure, divided by its original length, and multiplied by 100. It provides information on the material's ductility, flexibility, and ability to undergo plastic deformation without breaking.

A material with a high elongation at break value indicates that it can undergo significant deformation before failure, whereas a material with a low elongation at break value is more brittle and prone to fracture (Molded Dimensions, 2019). Elongation at break is an important parameter for characterizing the toughness and ductility of a material, including polymers. In the stress-strain curve, the elongation at break is typically measured at the point of failure, which is the point where the stress drops sharply after reaching the UTS and the material breaks. The elongation at break can vary depending on the type of material, its composition, processing conditions, and testing parameters.

### **2.8.3 Young's Modulus**

Young's modulus, also known as modulus of elasticity or tensile modulus, is a measure of the stiffness or rigidity of a material in the linear elastic range. It is defined as the ratio of stress to strain within the elastic limit of a material. Mathematically, Young's modulus can be expressed in **equation 2.2** (Young's Modulus, 2023).

$$\text{Young's modulus, } E = \frac{\text{Stress, } \sigma}{\text{Strain, } \varepsilon} \quad (\text{Equation 2.2})$$

Stress ( $\sigma$ ) is the force applied to a material per unit area, typically measured in Pascals (Pa) or mega pascals (MPa). Strain ( $\varepsilon$ ) is the change in length or deformation of a material per unit length, typically expressed as a dimensionless quantity or as a percentage.

Young's modulus is a fundamental material property that describes how a material responds to applied stress by deforming or elongating. It quantifies the material's stiffness, or resistance to deformation, in the linear elastic range, where the material returns to its original shape once the stress is removed. A higher Young's modulus indicates a stiffer material, while a lower Young's modulus indicates a more flexible or compliant material (Young's Modulus, 2023).

## 2.9 Biodegradation Study

Biodegradation study is a scientific investigation that aims to understand the natural breakdown or decomposition of a material by biological processes, typically carried out by microorganisms such as bacteria, fungi, and other living organisms. It involves evaluating the extent, rate, and mechanisms of bio-degradation of a material,

and may be conducted in various environmental conditions, such as soil, water, or other natural settings.

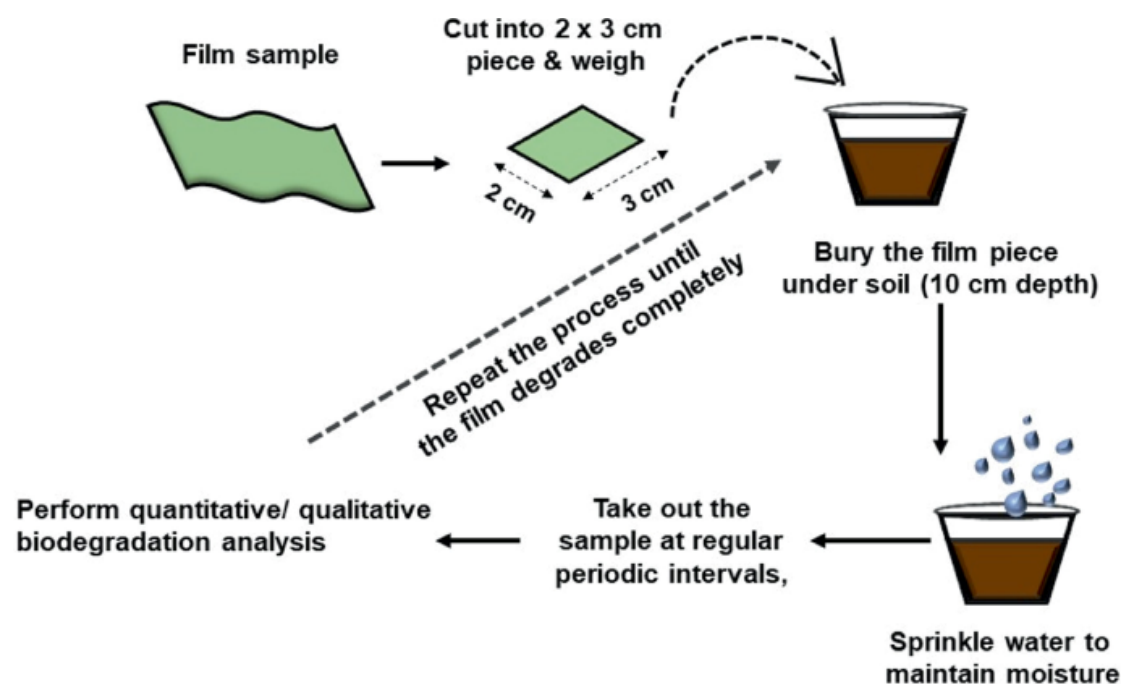
### **2.9.1 Soil Burial Test**

Soil burial test, also known as soil bio-degradation test or soil degradation test, is a type of environmental testing that measures the biodegradability or breakdown of a material in soil. It is commonly used to evaluate the environmental impact and sustainability of materials, especially those that are intended to be disposed of in soil, such as biodegradable polymers, agricultural films, and other organic or bio-based materials.

In a soil burial test, the material of interest is buried in soil, typically in controlled laboratory conditions or in field settings, and monitored over a period of time to assess its degradation or bio-degradation behavior. The test involves measuring various parameters such as weight loss, changes in physical properties, and changes in chemical composition of the material as it undergoes degradation in the soil environment (Al-Zahrani et al, 2017). Soil burial tests provide valuable information about the environmental fate of materials and their potential to break down into harmless substances in soil. The results of soil burial tests can be used to evaluate the effectiveness of materials in terms of their biodegradability, compostability, and environmental impact (Suharta et al, 2021). It can also help in the development and optimization of materials with improved environmental performance, and in assessing their suitability for specific applications or disposal scenarios.

The soil burial test is a widely used method to assess the bio-degradation of materials in a simulated soil environment. The procedure typically involves several steps. First, the test samples of the material to be evaluated are prepared, ensuring they are representative in terms of composition, size, and shape (Nazir et al, 2018). Next, an appropriate soil type, similar to the expected environmental conditions, is selected. The test samples are then buried in the soil at a predetermined depth in a randomized and replicate manner. Periodic monitoring is conducted over time, which

may include visual observations, measurements of weight loss, changes in physical or mechanical properties, and analysis of chemical or microbial changes in the soil and samples. Data on the changes observed in the buried samples and the surrounding soil are recorded and collected. The collected data is then analyzed to assess the extent and rate of bio-degradation, which may involve statistical analysis, comparison with control samples or reference materials, and interpretation of the results (Nazir et al, 2018). Finally, a comprehensive report is prepared summarizing the experimental setup, methods, results, and conclusions of the soil burial test, including details of the test conditions, sample preparation, monitoring procedures, and data analysis.



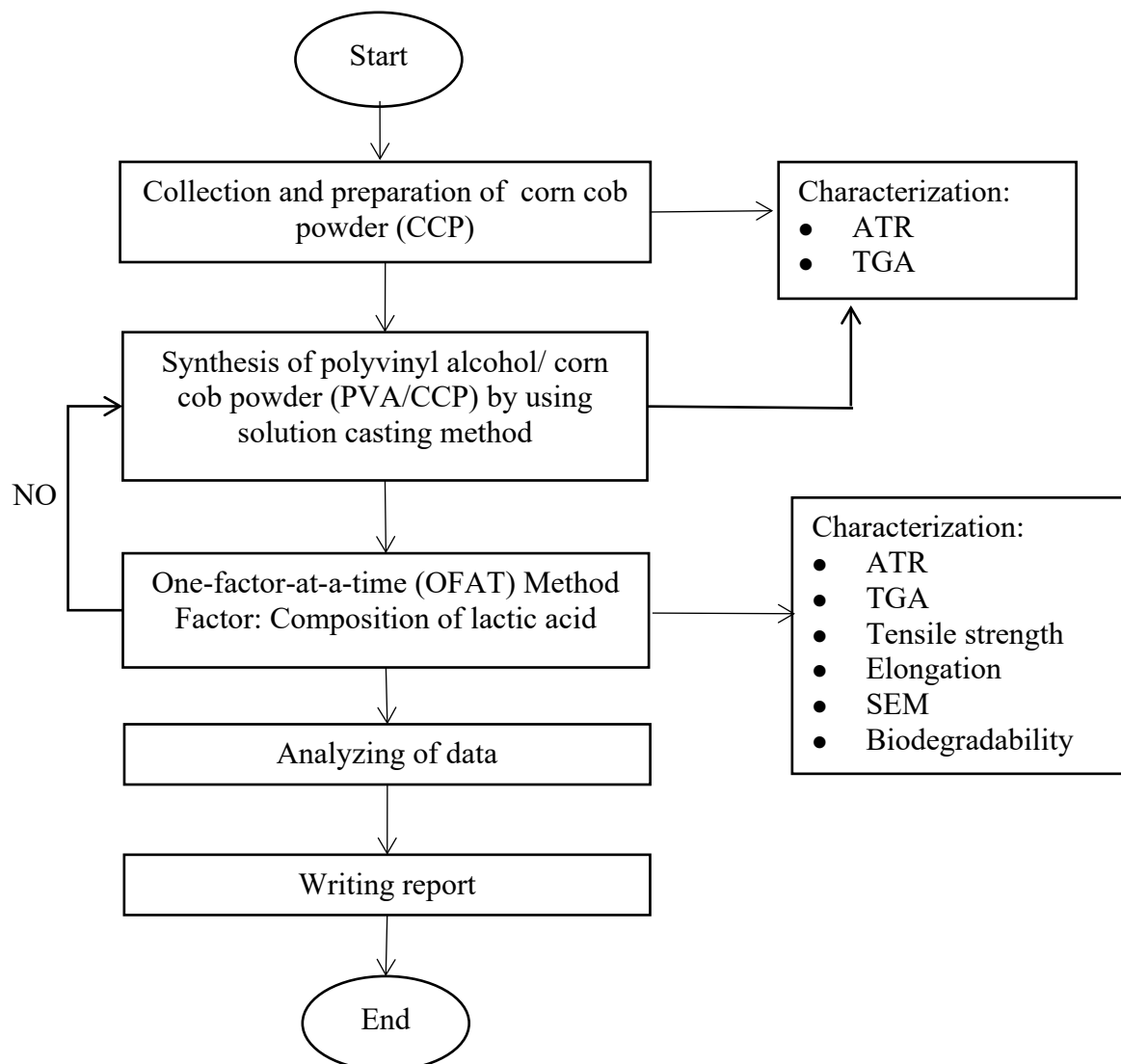
**Figure 2.15:** Method of Soil Burial Test (Suharta et al, 2021)

## CHAPTER 3

### METHODOLOGY

#### 3.1 Process Flow Chart

Figure 3.1 shows the overall process flow chart of this study.



**Figure 3.1:** Overall Process Flow Chart

### 3.2 List of Materials and Chemicals

The **Table 3.1** shows the list of all the materials and chemicals used in this study.

**Table 3.1:** Materials and Chemical List

<b>Materials and Chemicals</b>	<b>Description</b>
Corn Cob Powder	Act as a filler in blended film.
Polyvinyl Alcohol	Act as the main polymer in blended film.
Lactic Acid	Act as plasticizer in blended film.

### 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.

<b>Equipment and Apparatus</b>	<b>Description</b>
Beaker	Used place the mixture, solution and chemicals.
Glass plate	Used to cast the PVA/CCP solution.
Hot plate stirrer	Used to mix and heat the PVA/CCP solution.

Measuring cylinder	Used to measure the composition or amount of chemicals .
Weight balance	Used to measure the composition or amount of the CCP and lactic acid.
Magnetic bar	Used to stir the mixture.
Tray	Used to dry the CCP.
Water bath	Used to heat PVA/CCP solution.
Drying oven	Used to dry the CCP before film Production
Dumbbell cutter	Used to cut the PVA/CCP blended film into dumbbell for tensile and soil burial test.
Digital micrometer	Used to measure the thickness of PVA/CCP blended film.
Tensile tester	Used to determine the tensile strength of PVA/CCP blended film.
Fourier transform infrared spectroscopy (FTIR) -Attenuated total reflectance spectroscopy (ATR)	Used to determine the functional group of CCP and PVA/CCP blended film.
Thermogravimetric analysis (TGA)	Used to determine thermal properties of PVA/CCP blended film.

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### 3.4 Collection and Preparation of Raw Material

The three main raw materials used in this study are polyvinyl alcohol (PVA), lactic acid and corn cob powder (CCP). To remove moisture from the CCP, it was dried in an oven at 60 °C for approximately 24 hours. Then store it in a dry place for later use. Meanwhile, 99.5% pure PVA and lactic acid have been ordered from Sigma Aldrich.

### 3.5 Production of PVA/CCP Blend Film by Using Solution Casting Method

First, 100 mL of distilled water was added to 80 wt% PVA powder in a 250 mL beaker. Then, a magnetic bar was used to stir the solution at constant speed for 30 minutes while stirring with a hot plate until all the PVA was dissolved. According to Yee Ling's study, the solution must be stirred at a constant temperature of 90 °C. Meanwhile, 25 mL of distilled water and 2 g of CCP were combined in a 100 mL beaker and stirred at 35 °C for 30 min. The CCP solution and the lactic acid, the composition of which is listed in **Table 3.3**, were then added together and the mixture was continuously stirred in the beaker. After combining the PVA solution and the CPP dispersion, the mixture was placed in a water bath to remove all bubbles and foam. The PVA/CCP solution was poured onto a clean glass plate and allowed to dry at room temperature for 24 hours. According to Tarique et al (2021) the combined film was then dried in an oven at 30 °C for 30 minutes. The pooled membrane was then stored at room temperature for further examination (Tarique, Sapuan, & Khalina, 2021). The same steps were repeated with different lactic acid compositions. The formation of PVA/CCP composite films according to composition is shown in **Table 3.3**.

**Table 3.3:** Formulation of Prepare PVA/CCP Blend Films.

Blend	PVA (% w/v)	CCP (%w/v)	Lactic Acid (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

By stabilizing an input variable, the OFAT method should discover the ideal state of the second variable. The composition of the lactic acid is a crucial factor in this study. PVA and CCP will continue to weigh 80% and 20%, respectively. The only variable that varies is the amount of lactic acid, which varies from 0 to 2.0 m. Standard values were recorded after testing three replicates.

### 3.7 Testing and Analysis

The composition of the PVA/PCC blended film was examined using fourier transform infrared spectroscopy (FTIR) attenuated total reflectance (ATR) spectroscopy method, thermogravimetric analysis (TGA). Beside, the mechanical properties of the PVA/CCP blended film were examined using the tensile tester. In addition, the biodegradable properties of the PVA/CCP blended film were examined using the soil burial test.

#### 3.7.1 Attenuated Total Reflectance Spectroscopy (ATR)

A technique called fourier transform infrared spectroscopy (FTIR), attenuated total reflectance spectroscopy (ATR) is utilized to identify various functional groups that were present in the CCP and PVA/CCP blended film. In this study, the Perkin

Elmer Spectrum Two was employed, and Figure 3.2 depicted this mode. Before beginning the analysis, the diamond cell was cleaned with isopropanol alcohol. The CCP was then made in the appropriate quantity and deposited on the diamond cell. The sample is pressed forcefully against the crystal by the pressure town until the pressure gauge on the software programme reads the ideal level of pressure, which is between 70 and 80%. Normally, the ATR spectra analysis was measured within the wavelength range of  $400 - 4000 \text{ cm}^{-1}$  with a resolution of  $4 \text{ cm}^{-1}$  for 32 scans (Kałużna et al, 2019). After finishing the CCP analysis, all the stages were redone using a different PVA/CCP blended film with a different composition.



**Figure 3.2:** Perkin Elmer Spectrum Two (Kaluzna et al, 2019)

### 3.7.2 Thermogravimetric Analysis (TGA)

The thermal stability and volatility of the PVA/CCP blended film are evaluated using thermodynamic analysis. The thermal stability of the PVA/CCP blended film is measured, including the amount of filler, the amount of solvent still present, the decomposition temperature of the stabilizer (García-Márquez et al, 2012). To achieve the result, TGA constantly weighs and modifies the PVA/CCP blended film at a constant heating rate. Small piece of PVA/CCP blended film undergoes this analysis by using the nitrogen environment with a flow rate of  $20 \text{ mL/min}$  and the heating rate is constant which is  $10 \text{ °C/min}$ . The temperature rises from  $30 \text{ °C}$  to  $600 \text{ °C}$  after the initial heating. The TGA parser is shown in **Figure 3.3**.



**Figure 3.3:** TGA Analyzer (García-Márquez et al, 2012)

### 3.7.3 Tensile Tester

PVA/CCP blended film's tensile strength, elastic modulus, and elongation at break were measured using a Tinius Olsen H10KS-0784 tensile tester. Before the tensile test began, a dumbbell cutter was used to prepare 5 specimens in the shape of dumbbells with an average thickness of 0.64 mm. The 5 specimen perform the tensile test in the tensile tester at cross head speed of 20 mm/min. At the stress-strain curves, the results of the tensile strength, elastic modulus, and elongation at break were displayed. To obtain an average, the other four dumbbell shape specimens were repeated. The Tinius Olsen H10KS-0784 tensile tester is depicted in **Figure 3.4**.



**Figure 3.4:** Tinius Olsen H10KS-0784 Tensile Testing Machine (Roell, 2022).

### 3.7.4 Scanning Electron Microscopy (SEM)

A focused electron beam is used in scanning electron microscopy (SEM), a type of microscopy, to scan the surface of materials and produce high-resolution images. According to TWI(2022) study, the SEM image can be used to show details about the surface topography and composition of a particular material. To conduct the study, a PVA/CCP/lactic acid blended film sample was placed on the SEM device. The cross-section area of the PVA/CCP/lactic acid blended film would be scanned by a concentrated electron beam. **Figure 3.5** shows the SEM device.



**Figure 3.5:** SEM device (TWI, 2022)

### 3.7.5 Biodegradability Test

A soil burial test was used to test the biodegradability. This test will determine whether PVA/CCP blended film and non-biodegradable plastic bag film are biodegradable. Oxygen, ambient contaminants, and temperature changes interact with the biodegradability test, which can deteriorate physical, mechanical, and chemical qualities. Prior to being buried in the ground, the PVA/CCP blended and regular plastic film were first cut into dumbbell shapes and their weights were measured. After that, I discovered the nitrogen-rich soil. A container was used to store 200g of soil after it was measured. Under the conditions of a room, the samples were buried in the soil for two weeks. Every week, the weight of the films was determined and recorded. The percentage of degradation of PVA/CCP/lactic acid blended film was calculated by using the weight loss which shown in the **Equation 3.1** (Marichelvam, 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

$w$  = Weight of the film after

## CHAPTER 4

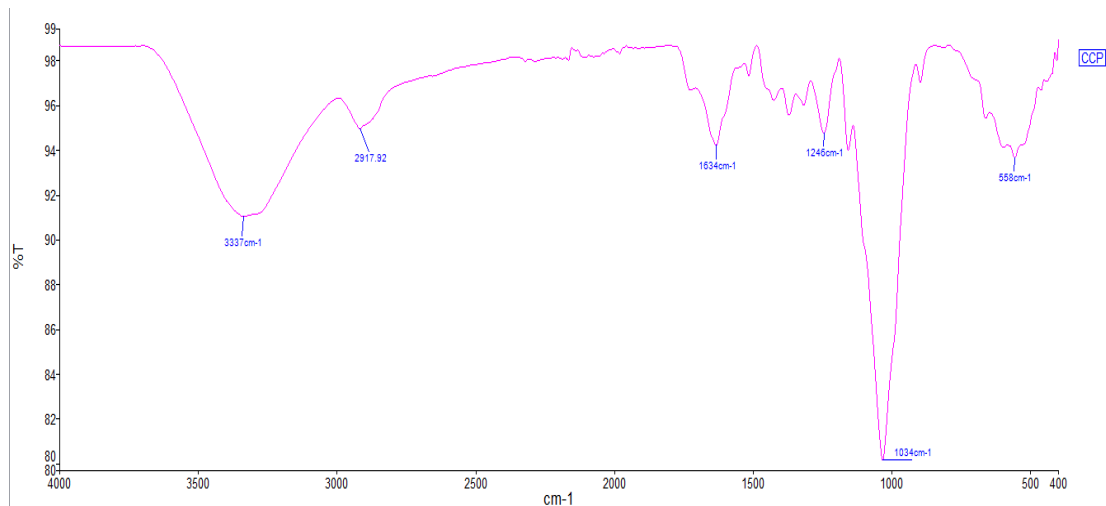
### Result and Discussions

#### 4.1 Characterization of PVA/CCP/Lactic Acid Blend Films

The PVA/CCP blended were characterized using fourier transform infrared spectroscopy (FTIR) which using attenuated total reflectance spectroscopy (ATR) method, thermogravimetric analysis (TGA), scanning electron microscopy (SEM), biodegradability testing, and mechanical properties testing.

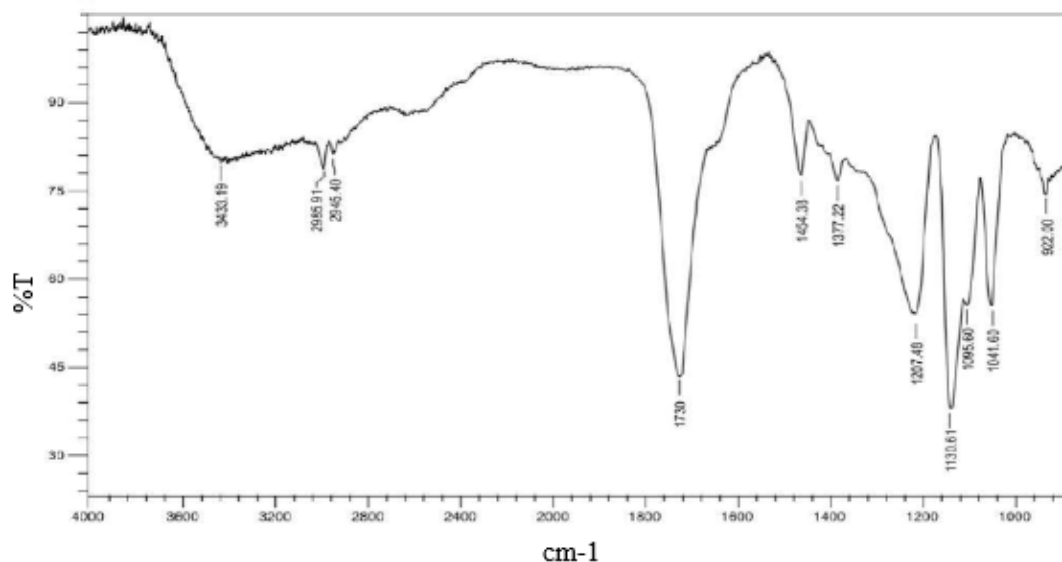
##### 4.1.1 Attenuated Total Reflectance (ATR) Spectroscopy

Fourier transform infrared spectroscopy (FTIR), attenuated total reflection (ATR) spectroscopy was used to verify the functional groups present in both the PVC and the mixed PVA/CCP/lactic acid film. When identifying the functional groups in the PVA/CCP/lactic acid mixed film, however, these were only detectable in the spectral range from  $1,500\text{ cm}^{-1}$ . This limitation stems from the fact that the region below  $1,500\text{ cm}^{-1}$  is commonly referred to as the “fingerprint region”, where individual peak identification is difficult due to the large number of peaks present in this range. *Figure 4.1* showed the FTIR spectra for CCP, it showed that CCP had a broad peak at  $3337\text{ cm}^{-1}$ , which corresponding to the stretching of the O-H bond due to the intramolecular hydrogen bonding of cellulose. Beside, there was a narrow peak attributed to the C=C stretch bond at  $558\text{ cm}^{-1}$ .

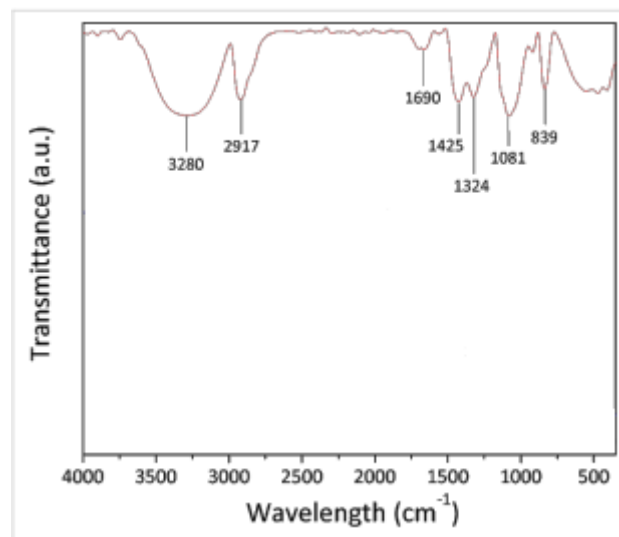


**Figure 4.1:** FTIR Spectra for CCP

**Figure 4.2** showed the FTIR spectra for lactic acid which was extract from study of Aseel and Hussein (2019). It showed a characteristic peak attributed to C=O bond at 1730 cm<sup>-1</sup>. Besides, it also showed a narrow peak, which represent to CH<sub>2</sub> stretching bond at 2945 cm<sup>-1</sup>.

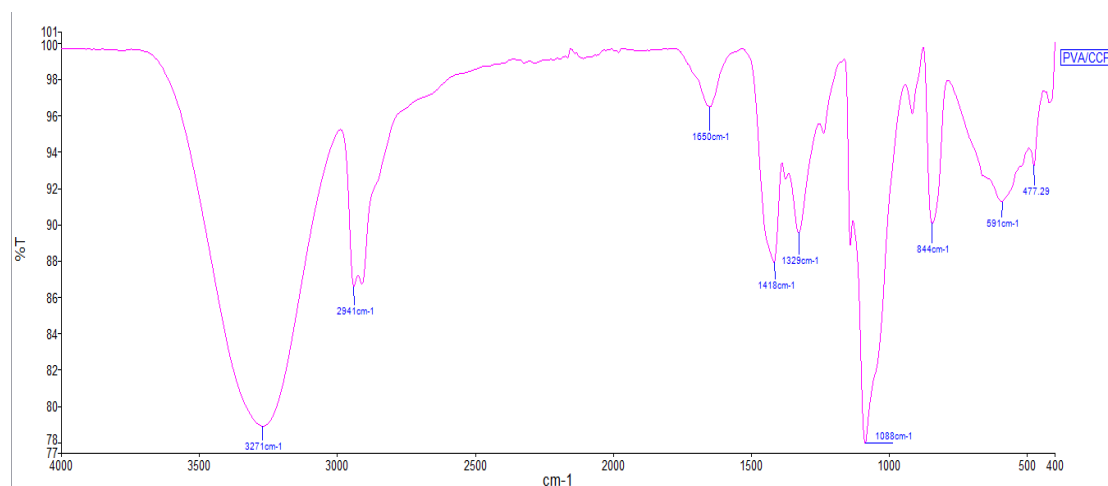


According to the study from Alireza (2015), it stated that the PVA obtain a broad peak at 3280 cm<sup>-1</sup>, which corresponding to the O-H stretching bond. In the other way, PVA had two narrow peak at 1324 cm<sup>-1</sup> and 839 cm<sup>-1</sup>, which corresponding to C-H deformation and C=C stretching bond which showed in **Figure 4.3**.



**Figure 4.3:** FTIR Spectra for Pure PVA Film (Alireza, 2015)

**Figure 4.4** showed the spectra of ATR for PVA/CCP/lactic acid blended film. According to the FTIR spectra of **Figure 4.4**, the PVA/CCP blended film show a board peak at  $3271\text{ cm}^{-1}$  and two narrow peak at  $1329\text{ cm}^{-1}$  and  $844\text{ cm}^{-1}$ .

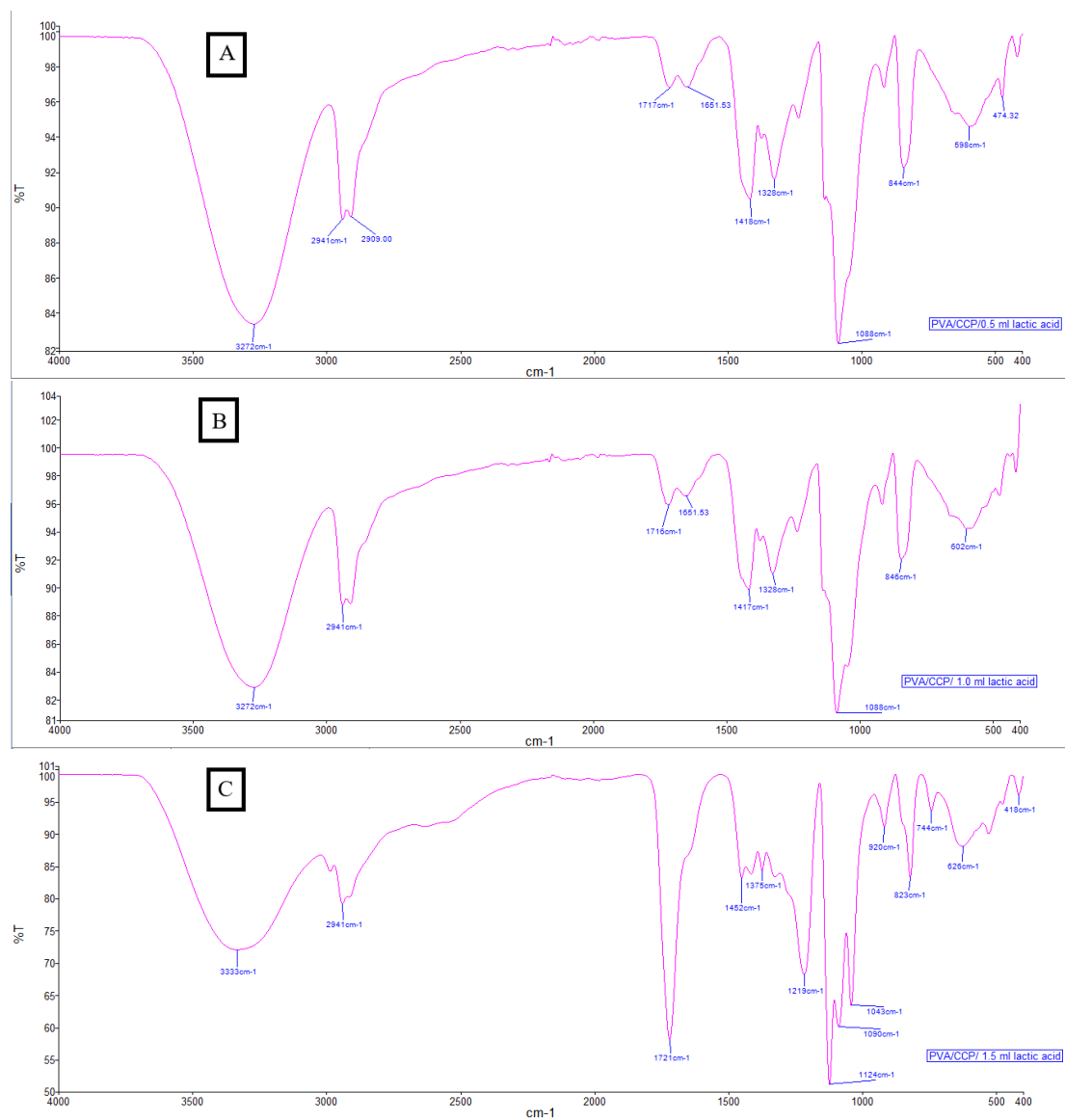


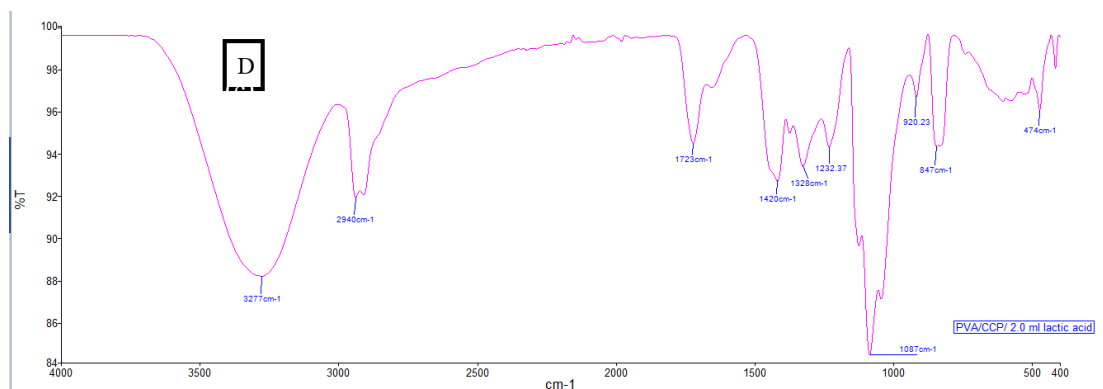
**Figure 4.3:** Spectra of ATR for PVA/CCP

**Figure 4.4** showed spectra of ATR for PVA/CCP/lactic acid blended film with different amount of lactic acid loading. From the IR spectra of **Figure 4.4(a)**, which was PVA/CCP/lactic acid blended film with 0.5 ml lactic acid, it show a board peak at  $3272\text{ cm}^{-1}$ . Beside, it had two narrow peak at  $1418\text{ cm}^{-1}$  and  $1717\text{ cm}^{-1}$ . The peak at



2941  $\text{cm}^{-1}$  attributed to the C-H stretching bond. In the other hand, the peak at 844 $\text{cm}^{-1}$  was corresponding to the C=C stretching bond. The presence of the C-H stretch bond indicated the presence of both cellulose and hemicellulose in the blended film. In addition, the other PVA/CCP/lactic acid blended films showed very similar infrared spectra to the **Figure 4.4(a)**, despite variations in their lactic acid content. Meanwhile, **Table 4.1** provides a summary of the infrared absorption peaks for the CCP, PVA/CCP and each of the PVA/CCP/lactic acid blended films. Above all, there was a increasing in the C=O stretching bond compare to the PVA/CCP and PVA/CCP with different composition of lactic acid





**Figure 4.4:** Spectra of ATR for PVA/CCP/Lactic Acid Blended Film with Different Composition of Lactic Acid Loading (A: Blended film with 0.5 ml of lactic acid, B: Blended film with 1.0 ml of lactic acid, C: Blended film with 1.5 ml of lactic acid, D: Blended film with 2.0 ml of lactic acid).

**Table 4.1** Infrared absorption peaks for the CCP, Lactic Acid, PVA and PVA/CCP Blended Film

Functional group	Wavelength (cm <sup>-1</sup> )			
	CCP	Lactic Acid	PVA	PVA/CCP
O-H stretching	3337	3280	3280	3271
CH <sub>2</sub> asymmetric stretching	2918	2985	2917	2914
C=O carbonyl stretching	1634	1730	1690	1650
C-H deformation	-	1404	1425	1418
C-O stretching	1034	1095	1081	1088

**Table 4.2** Infrared absorption peaks for the CCP, PVA/CCP and each of the PVA/CCP/Lactic Acid Blend Film

Functional group	Wavelength (cm <sup>-1</sup> )				
	PVA/CCP	PVA/CCP with 0.5 lactic Acid	PVA/CCP with 1.0 lactic Acid	PVA/CCP with 1.5 lactic Acid	PVA/CCP with 2.0 lactic Acid

O-H stretching	3271	3272	3272	3333	3277
CH <sub>2</sub> asymmetric stretching	2914	2941	2941	2941	2940
C=O carbonyl stretching	1650	1717	1716	1721	1723
C-H deformation	1418	1418	1417	1417	1420
C-O stretching	1088	1088	1088	1088	1087

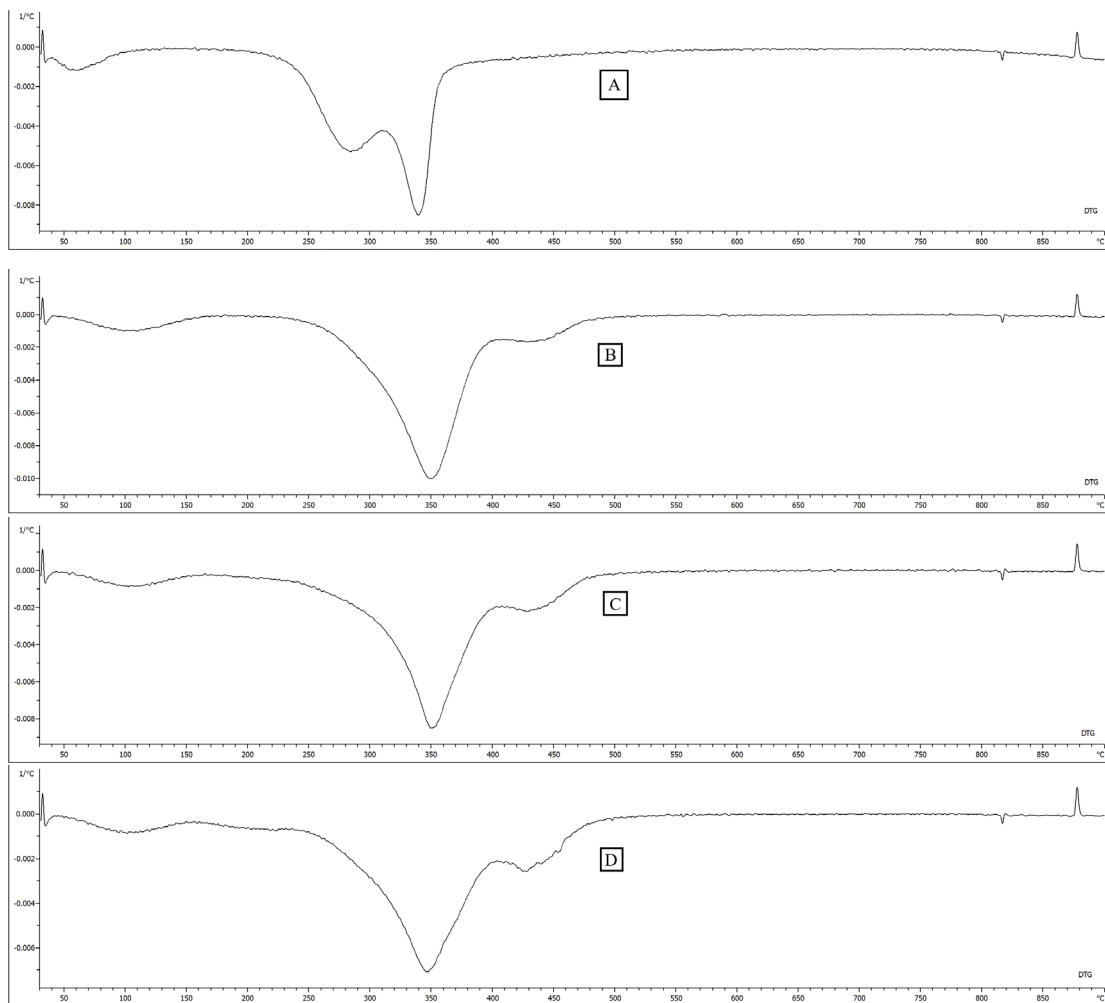
#### 4.1.2 Thermogravimetric Analysis (TGA)

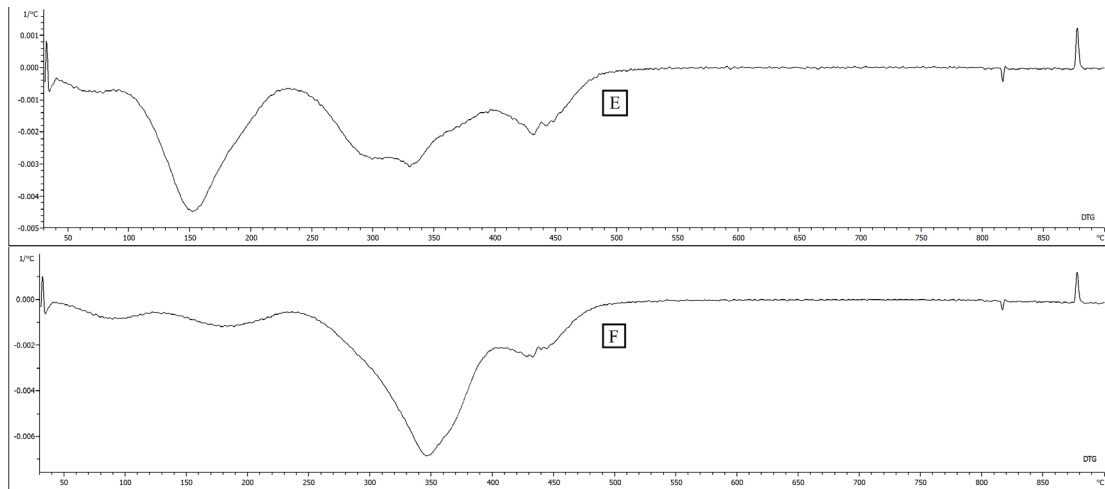
Thermogravimetric analysis (TGA) was used to evaluate the thermal properties of the PVA/CCP blended films. TGA is a fundamental analytical method for evaluating the thermal properties of a material. This involves continuously monitoring the weight of an accurately weighed sample in relation to temperature as it is placed in a controlled heating environment. TGA reveals weight loss events associated with processes such as dehydration, degradation, oxidation or volatilization. TGA provides important information about how materials respond to temperature changes.

Based on research done by Choo et al (2016), the weight loss profile of these films showed three main stages. In the initial phase, which took place at around 150 °C, moisture evaporated, including substances such as water and lactic acid. Second stage of weight loss, observed in temperature range between 200 °C and around 300 °C, it results from the film decomposition of the PVA/CCP blended, due to the thermal degradation of its polymer structure (Mahmoud, 2018). The final phase of weight loss, which occurs between 380 °C and around 500 °C, was attributed to the degradation of byproducts that generated by PVA during the thermal degradation process.

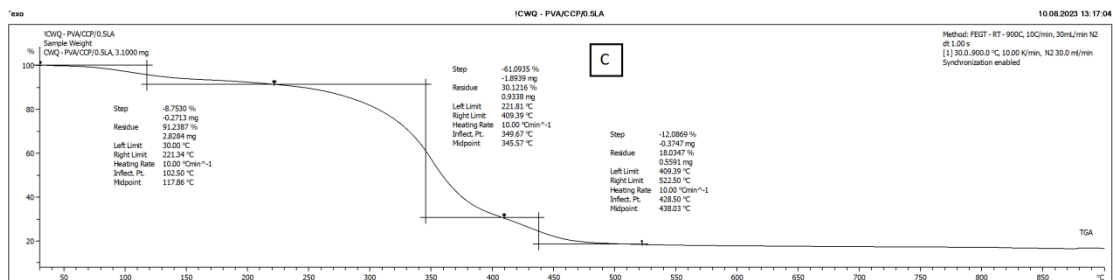
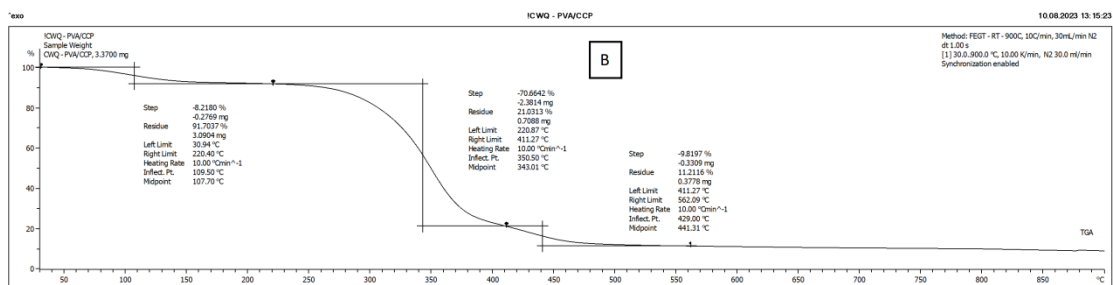
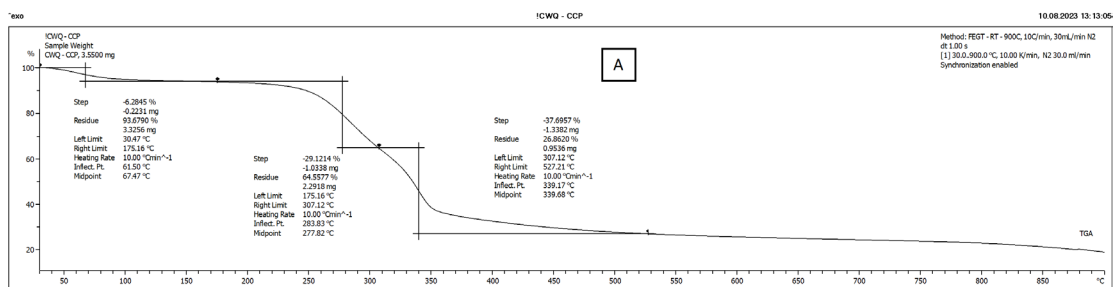
*Figure 4.5* shows the TGA result for all the CCP and all the PVA/CCP blended films. From the result, the thermal stability of PVA/CCP blended film is slightly increasing when the amount of lactic acid was increased. The thermal stability of the PVA/CCP matrix can be effect by increasing the free volume of plasticizer

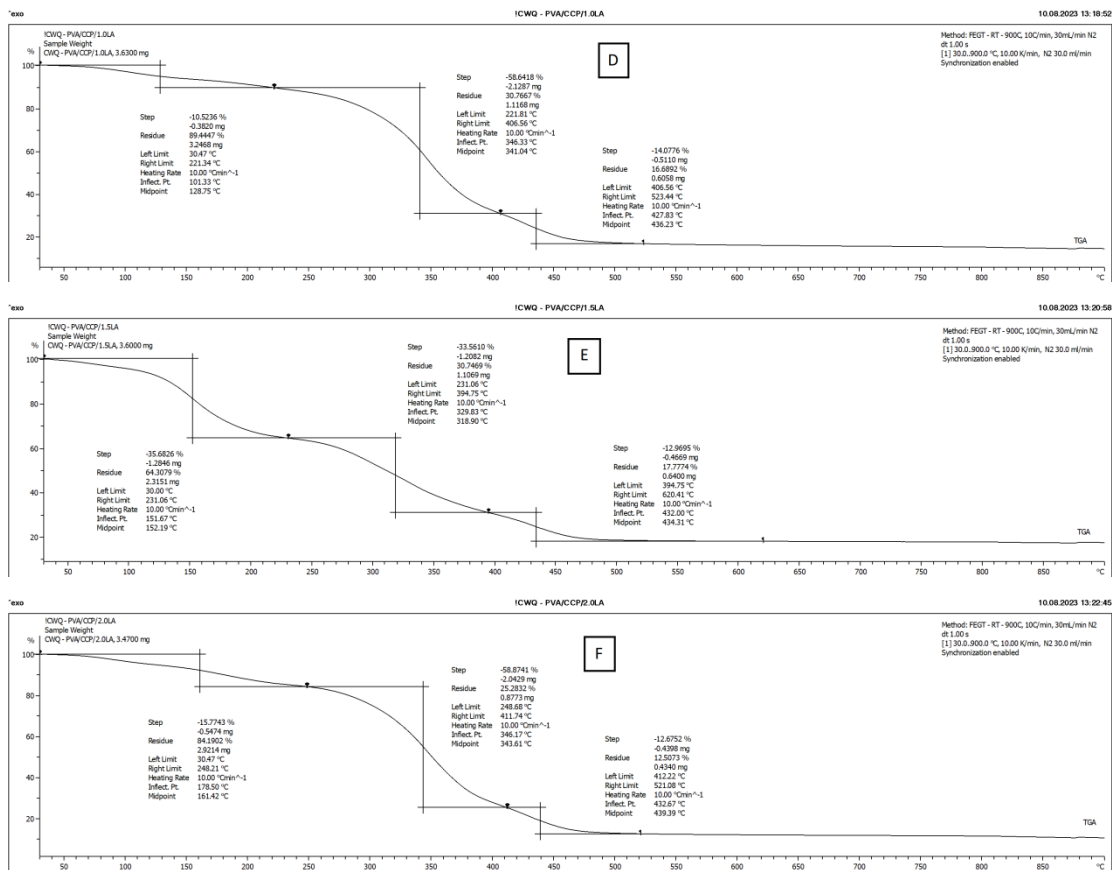
between the polymer chains and the chain spaced apart. At lower temperatures, polymer chains can slide past each other, thereby lowering the glass transition temperature ( $T_g$ ). According to Omnexus (2023), the glass transition temperature ( $T_g$ ) is a phenomenon of amorphous polymers. At this temperature, the glass-like state of the polymer changes to a rubber-like state. Plasticizer can reduce the risk of heat stress by lowering the  $T_g$ , thereby making the polymer more flexible at lower temperatures.





**Figure 4.5 (a):** TGA Result of CCP and PVA/CCP Blended Films (A:CCP, B: PVA/CCP blended film without lactic acid, C: PVA/CCP blended film with 0.5 ml of lactic acid, D: PVA/CCP blended film with 1.0 ml of lactic acid, E: PVA/CCP blended film with 1.5ml of lactic acid and F: PVA/CCP blended film with 2.0 ml of lactic acid).





**Figure 4.5 (b):** TGA Weight Loss Result of CCP and PVA/CCP Blended Films (A:CCP, B: PVA/CCP blended film without lactic acid, C: PVA/CCP blended film with 0.5 ml of lactic acid, D: PVA/CCP blended film with 1.0 ml of lactic acid, E: PVA/CCP blended film with 1.5 ml of lactic acid and F: PVA/CCP blended film with 2.0 ml of lactic acid).

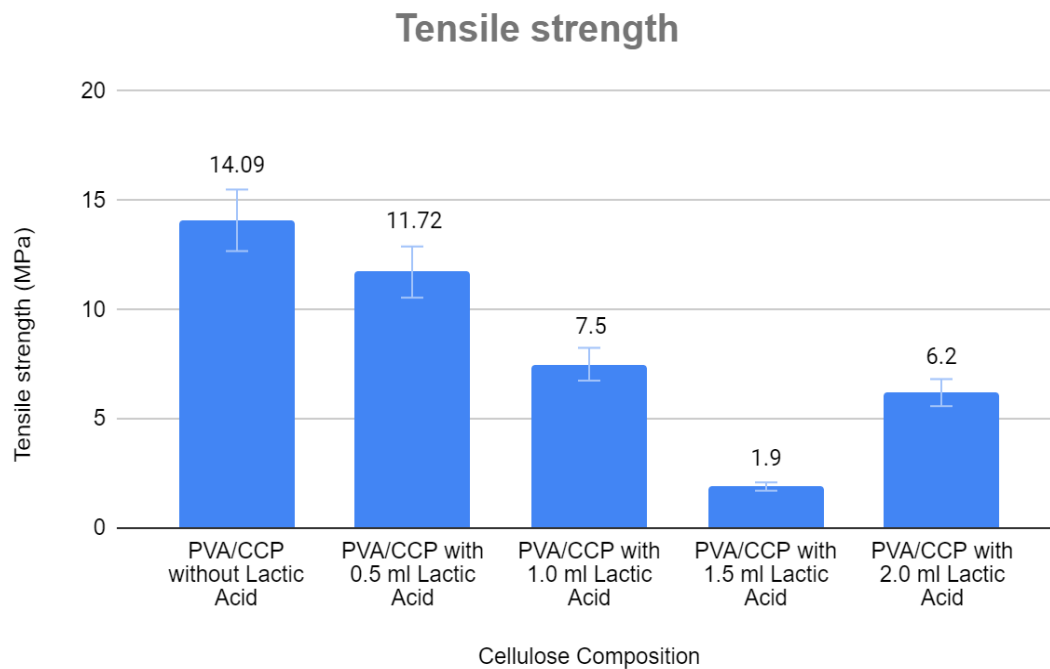
## 4.2 Mechanical Properties

All the PVA/CCP blended film were prepared in the form of dumbbell shape. Before the tensile test, the thickness of all PVA/CCP blended film was weight and the thickness was between 0.190 mm to 0.345 mm. To obtain an average result in terms of tensile strength, elongation at break and elastic modulus, the mechanical properties of the entire PVA/CCP blended film with different composition of lactic acid were tested 5 times.

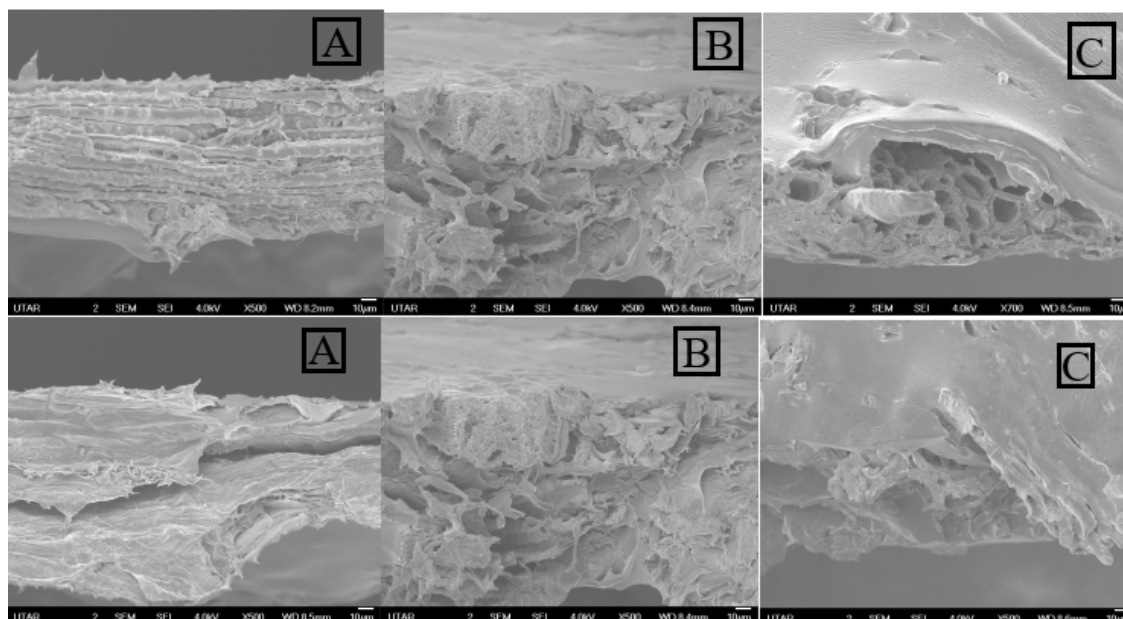
### 4.2.1 Tensile Strength

Based on preliminary study, the pure PVA film exhibited the tensile strength of 15.86 MPa. This value was higher than the PVA/CCP blended film due to the high crystalline structure of PVA. Additionally, Asrofi et al (2019) also reported that the structure of pure PVA triggers a well intramolecular network formation between its chain and thus resulting in good tensile properties. *Figure 4.6* showed the result of tensile strength for all PVA//CCP blended film with amount of composition lactic acid. Recording to the *Figure 4.6*, PVA/CCP without lactic acid had the highest tensile strength of 14.09 MPa. Meanwhile, PVA/CCP with 1.5 ml of lactic acid had the lowest tensile strength 1.9 MPa. This is because the PVA/CCP with 1.5 ml of lactic acid blended film had the highest flexibility and ductile. According to Muhammet (2021), as the tensile strength decreased, the flexibility increased accordingly. In addition, the tensile strength 6.2 MPa was obtained in the PVA/CCP with 2.0 ml of lactic acid blended film which was higher than the PVA/CCP with 1.5 ml of lactic acid. In theoretical, the lactic acid will act as a cross linking agent between the polymer chain and molecule of lactic acid and increasing in tensile strength (Marin, Joan & Yhorc, 2014). Due to the addition of corn cob powder, it disturb the lactic acid to react with the polymer chain. When the composition of lactic acid increased, the molecule of lactic acid was able to react with the polymer change thus it was increased in the tensile strength.

After the tensile test, the cross-sectional morphology of the PVA/CCP/lactic acid blended films with the lowest, medium and maximum tensile strengths was examined using scanning electron microscopy (SEM). According to *Figure 4.7*, which showed the cross section morphology of PVA/CCP blended film, by comparing PVA/CCP with 1.0 ml and 1.5 ml of lactic acid blended film, there was fibers occurs when the composition of lactic acid was increased.



**Figure 4.6:** Tensile Strength of PVA/CCP Blended Films.

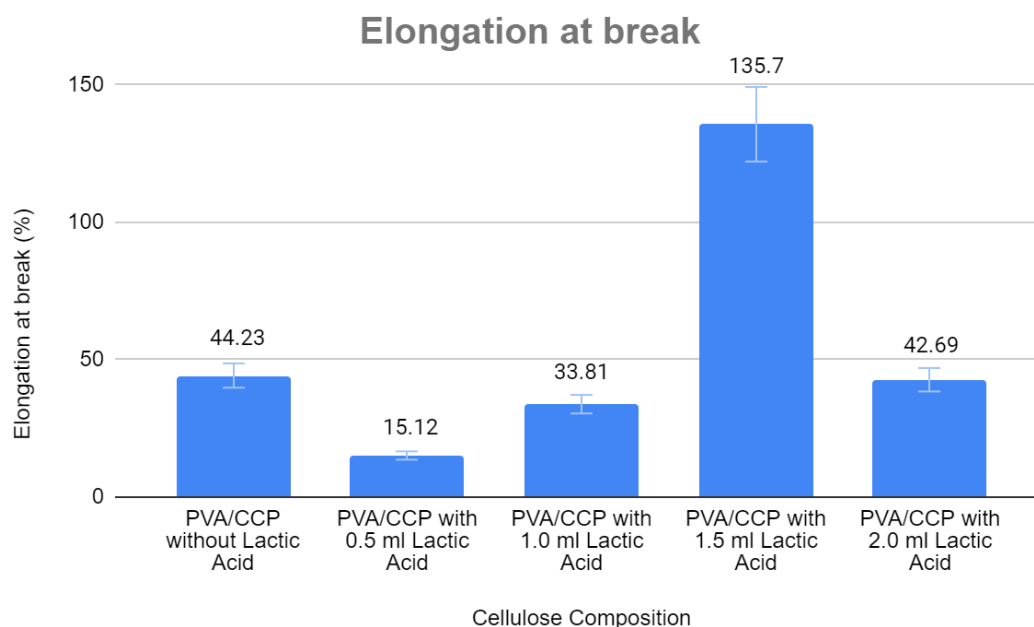


**Figure 4.7:** SEM image of Cross Section Area of PVA/CCP with different Composition of Lactic Acid Blended Film at 500x Magnification ( A: PVA/CCP (highest), B: PVA/CCP with 1.0 ml of lactic acid (moderate), C: PVA/CCP with 1.5 ml of lactic acid (lowest))



#### 4.2.2 Elongation at Break

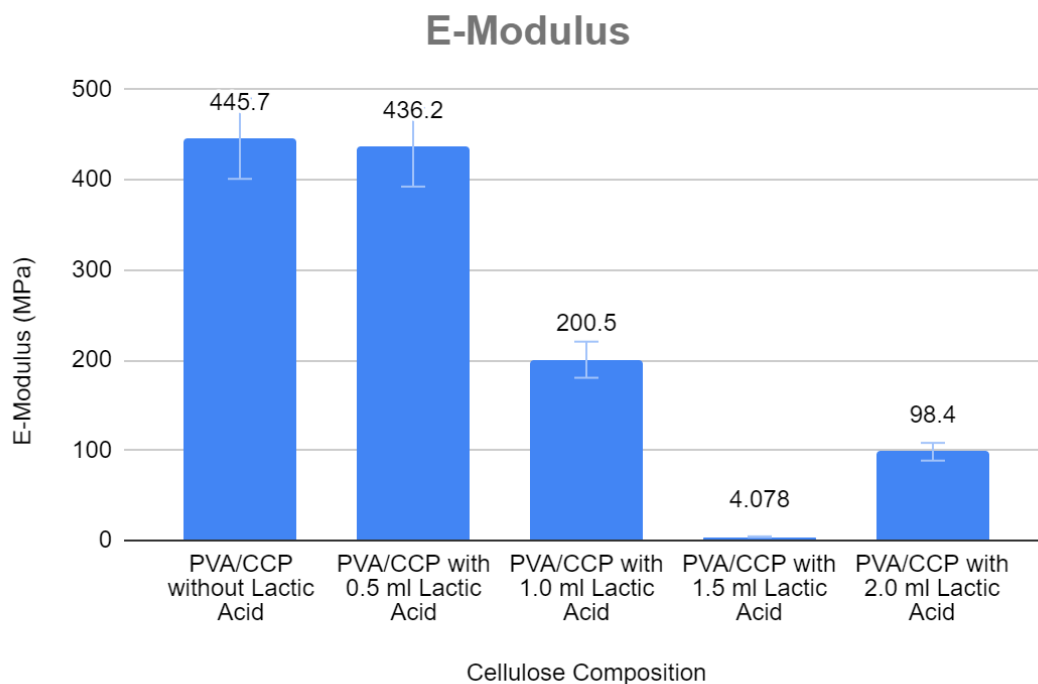
According to the result of PVA/CCP with different composition of lactic acid that showed in the **Figure 4.8**, the PVA/CCP with 1.5 ml of lactic acid had the highest elongation at break, which was 135.7%. PVA/CCP films without lactic acid exhibit a higher elongation at break. Elongation at break measures a material's ability to bend flexibly before fracture, while tensile strength measures a material's ability to withstand extensional pressures. Higher elongation at break values are common for materials with lower tensile strength (Muhammet Davut, 2021). In theoretical, as the concentration of lactic acid in the PVA/CCP mixture increases, lactic acid molecules become more accessible for cross-linking processes. (Sanyang, 2015). The elongation of polymeric materials depends on the mobility of their molecular chains. When the mobility of polymer chains can be reduced, thereby increasing the material's resistance to stress-induced deformation and failure. In this case, the polymer was forming the flexibility bonding between the molecule observe through FTIR with was C=O stretching bond.



**Figure 4.8:** Elongation at Break of PVA/CCP Blend Films.

### 4.2.3 Elastic Modulus

Elastic modulus used in measuring resistance in materials to elasticity or deformation. A lower value of elastic modulus means increased flexibility and reduced stiffness and measures a material's resistance to deformation under applied stress (StudySmarter UK, 2023). When introduced into polymers, lactic acid causes the formation of bonds between polymer chains. The elastic modulus is directly influenced by the flexible bond. In this scenario, due to the formation of fiber and flexible bonding, the elastic modulus was increased. When the composition of lactic acid increase, there was a cross linking formation between the lactic acid molecule and polymer chain, thus increase in the elastic modulus. From **Figure 4.9**, elastic modulus decreased when the composition of lactic acid increased. The PVA/CCP without lactic acid have the highest elastic modulus, which was 445.7 MPa. Meanwhile, the PVA/CCP with 1.5 ml of lactic acid have the lowest elastic modulus, which was 4.078 MPa.

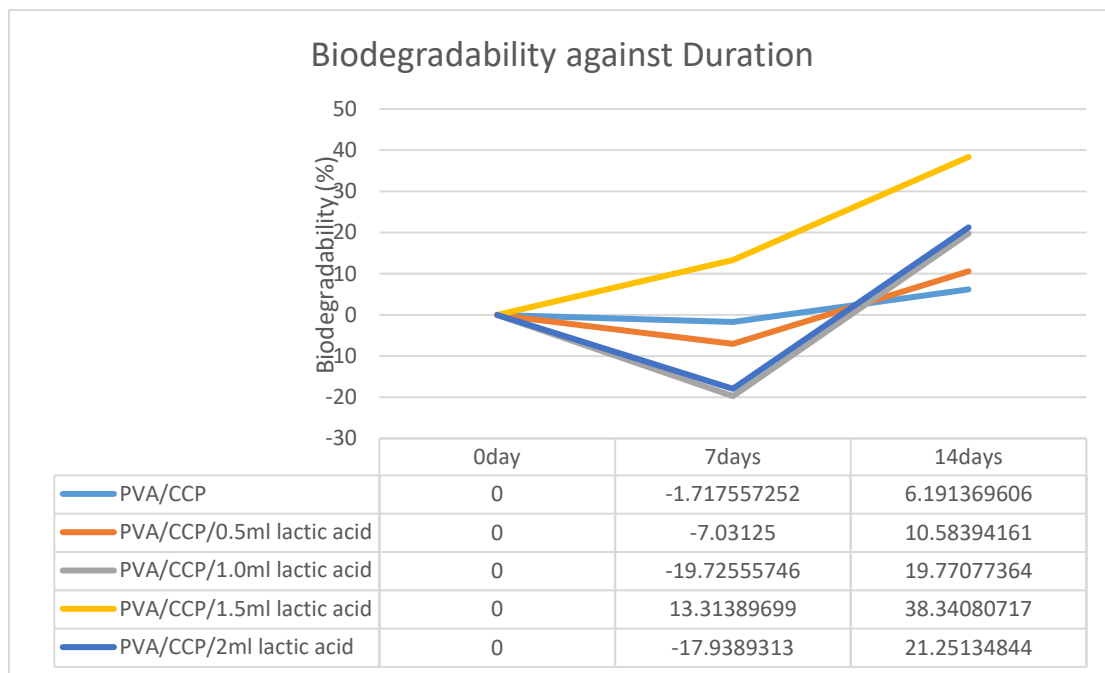


**Figure 4.9:** E-modulus of PVA/BPP Blend Films.

### 4.3 Biodegradability Test

Soil burial test normally was used to determine the biodegradability by weight loss of the substance. This test is carried out under various environmental conditions including sunlight, humidity, UV rays and rainfall. *Figure 4.10* showed the result of biodegradability test after 14 days. *Figure 4.10* shows that the biodegradability was decrease, because the PVA/CCP blended film has the potential to absorb water. When it comes to 14 days, the biodegradability was increased dramatically, this is because the hydrolysis process, in which water molecules break polymer chains (Abedini Najafabadi, 2021). The different composition of lactic acid was added to the PVA/CCP blended film , and this will increased water absorption, which can accelerate hydrolysis processes and lead to the breaking of PVA bonds. According to the result of *Figure 4.7*, the fibers and flexible bond allow the water molecule to move in to the polymer chain and undergo hydrolysis. In this case, there was higher change for microorganism to broke down.

According to *Figure 4.10*, the PVA/CCP/ 0.5 ml lactic acid showed the highest degradation rate, which was 38.34%. In the others hands, when the composition of lactic acid increase, the biodegradability was increase. The addition of lactic acid to a PVA/CCP composite film will potentially increase both hydrolysis and microbial activity.

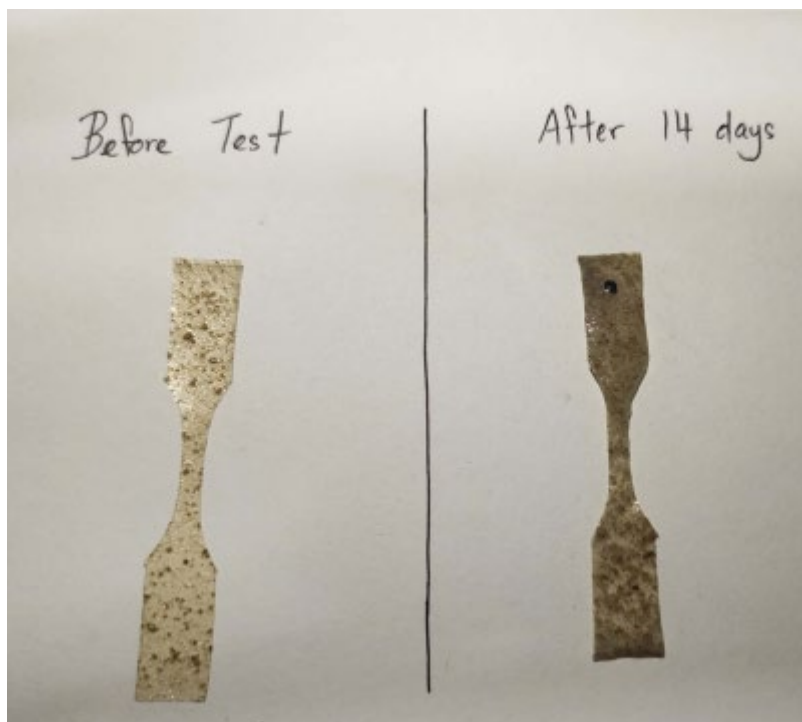


**Figure 4.10:** Result of Biodegradability Test.

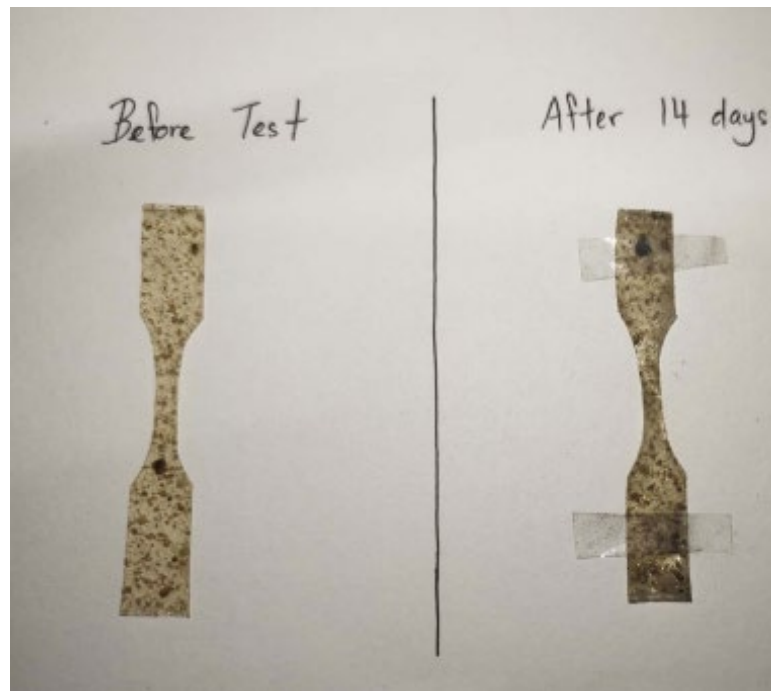
*Figure 4.11* showed the physical appearances of all the film. After the two-week biodegradability test, each film of the PVA/CCP blended shrank. The glow effect occurs because the mixed films can contract and expand slightly. When a PVA/CCP blended film is exposed to sunlight, it shrinks. Due to the hydrophilic polymer contained in the PVA/CCP mixed film, which can absorb water when it rains, the PVA/CCP mixed film swells in the meantime. Above all, PVA/CCP with 1.5 ml of lactic acid has the most obvious physical appearance within all blended film which showed in the *Figure 4.11(d)*.



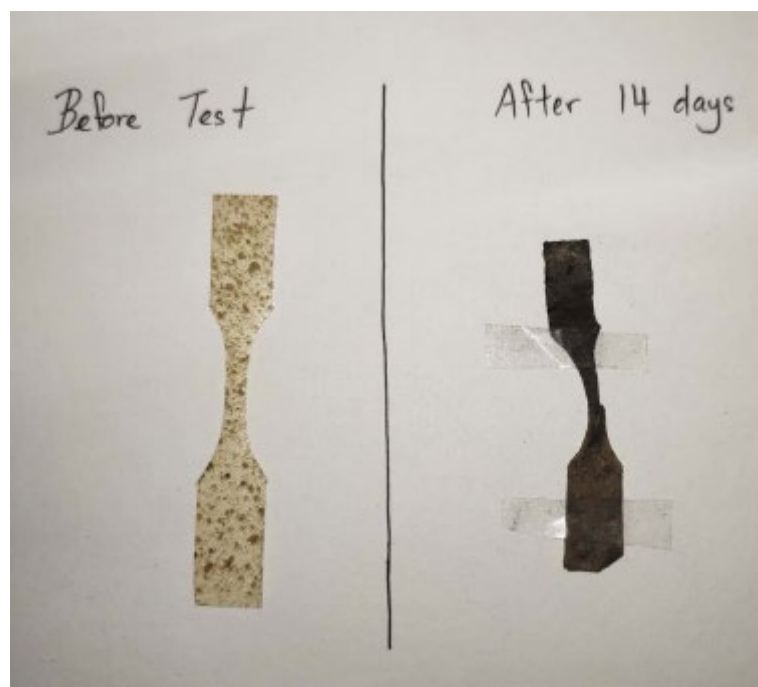
**Figure 4.11(a):** Biodegradability Test for PVA/CCP Blended Film without lactic acid



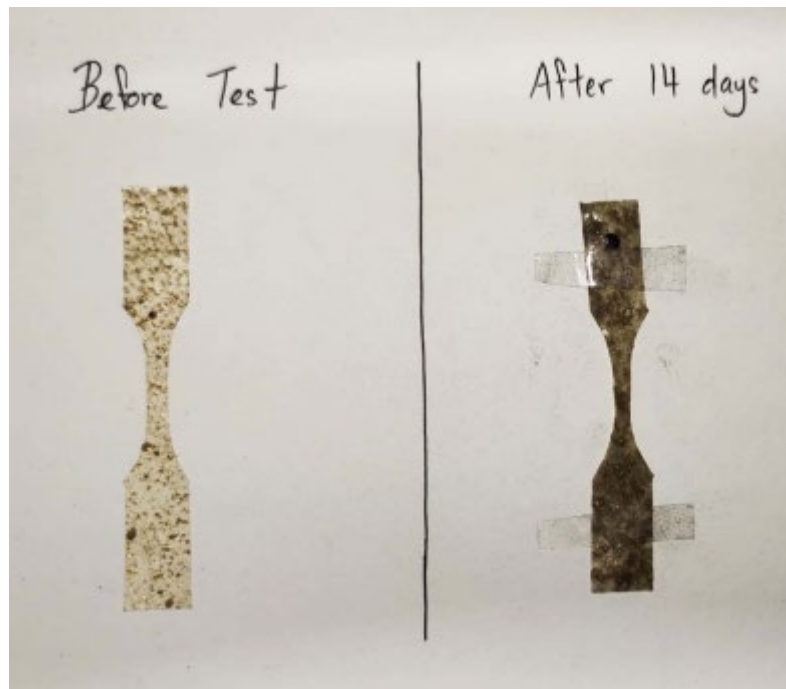
**Figure 4.11(b):** Biodegradability Test for PVA/CCP Blended Film with 0.5 ml of lactic acid



**Figure 4.11(c):** Biodegradability Test for PVA/CCP Blended Film with 1.0 ml of lactic acid



**Figure 4.11(d):** Biodegradability Test for PVA/CCP Blended Film with 1.5 ml of lactic acid



**Figure 4.11(e):** Biodegradability Test for PVA/CCP Blended Film with 2.0 ml of lactic acid

## CHAPTER 5

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Summary of Study

In this study, the blended film was prepared from a PVA/CCP/lactic acid blended film using the solution casting method. Blended was prepared by modifying the composition of lactic acid using the one-factor-at-a-time (OFAT) method.

Fourier transform infrared spectroscopy (FTIR) attenuated total reflectance (ATR) spectroscopy was used to identify the functional group of CCP and each PVA/CCP/lactic acid blended film. Beside, thermogravimetric. Analysis (TGA) was used to determine the thermal stability of CCP and each PVA/CCP/lactic acid blended films. The result show that the thermal stability of PVA/CCP blended film was slightly increased when the composition of lactic acid increased.

According to the results, the elastic modulus and tensile strength with the highest values were 14.09 MPa and 445.7 MPa, respectively, and the elongation at break value was 15.12%. After the tensile test, the cross-sectional morphology of the PVA/CCP/lactic acid blended films with the lowest, medium and maximum tensile strengths was examined using scanning electron microscopy (SEM). In addition, a soil burial test called biodegradability test was conducted to study the biodegradability. According to the results, among all the blended films, the films containing 2 ml of lactic acid had the highest biodegradability (38.34%).



## 5.2 Recommendation for Future Study

To improve the results and quality of this study, a number of factors related to manual skills could be improved or improved. The following list of suggestions included several:

- i. During preparation of PVA/CCP/lactic acid blended film, the composition of lactic acid was suggest from 0 to 4 ml to get a better more clearer picture on the effect of lactic acid of PVA/CCP blended film.
- ii. When the PVA/CCP/lactic acid solution was poured into the glass plate, the solution was ensured to be poured uniformly throughout the glass plate so that the thickness of the PVA/CCP/lactic acid blended film was uniform.
- iii. After pure the solution of PVA/CCP/lactic acid to the glass plate, ensure the table is flat to get a same thickness of the film.
- iv. Further characterizations of the CCP and PVA/CCP/lactic acid blended films can be performed by using pH testing and water permeability test and more characterization.
- v. For the biodegradability test, the duration for degradation of the PVA/CCP/lactic acid blended 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 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/CCP/lactic acid blended films.

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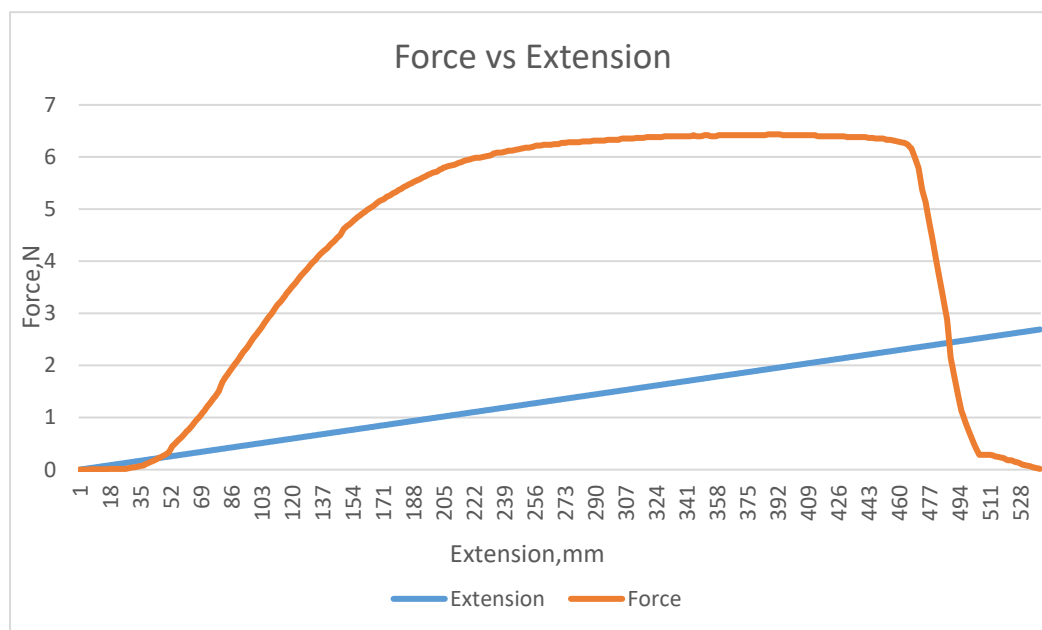


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## APPENDIX

### APPENDIX: Mechanical Properties

#### A. Force vs extension of PVA/CCP blended film.

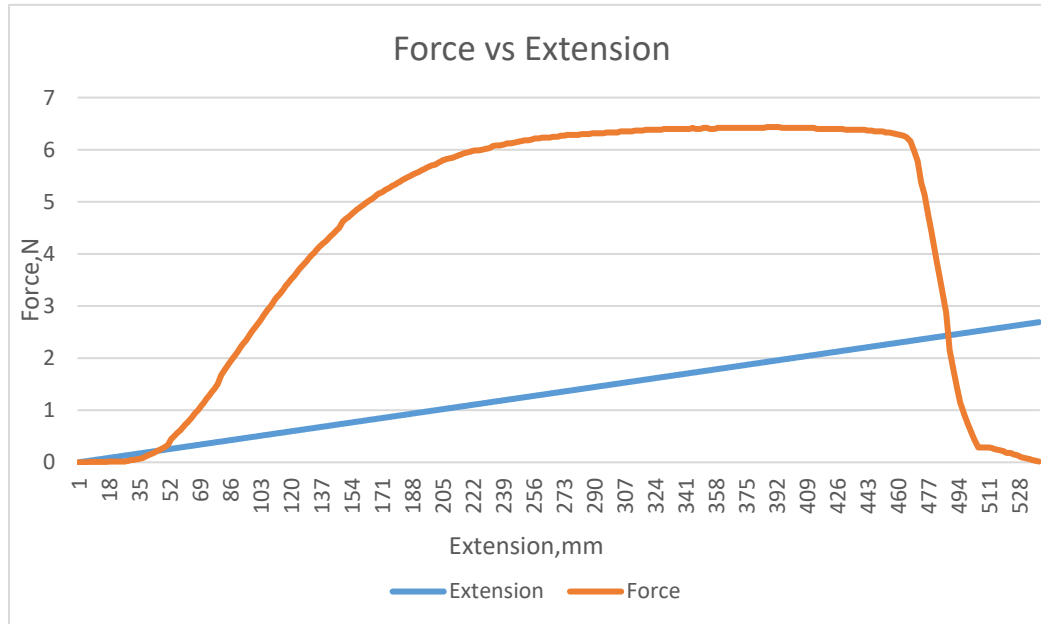


Summary of the data.

Specimen No	E-modulus, (MPa)	Tensile strength, (MPa)	Elongation at break, (%)
PVA/CCP(R1)	251.2	14.09	44.23
PVA/CCP(R2)	445.7	11.54	10.74
PVA/CCP(R3)	333.6	9.34	10.65
PVA/CCP(R4)	440.2	12.47	14.23
PVA/CCP(R5)	346	8.91	5.62
Mean	363.4	11.27	17.09
Std. Dev.	81.3	2.164	15.48
Median	346	11.54	10.74

Maximum	445.7	14.09	44.23
Minimum	251.2	8.91	5.62

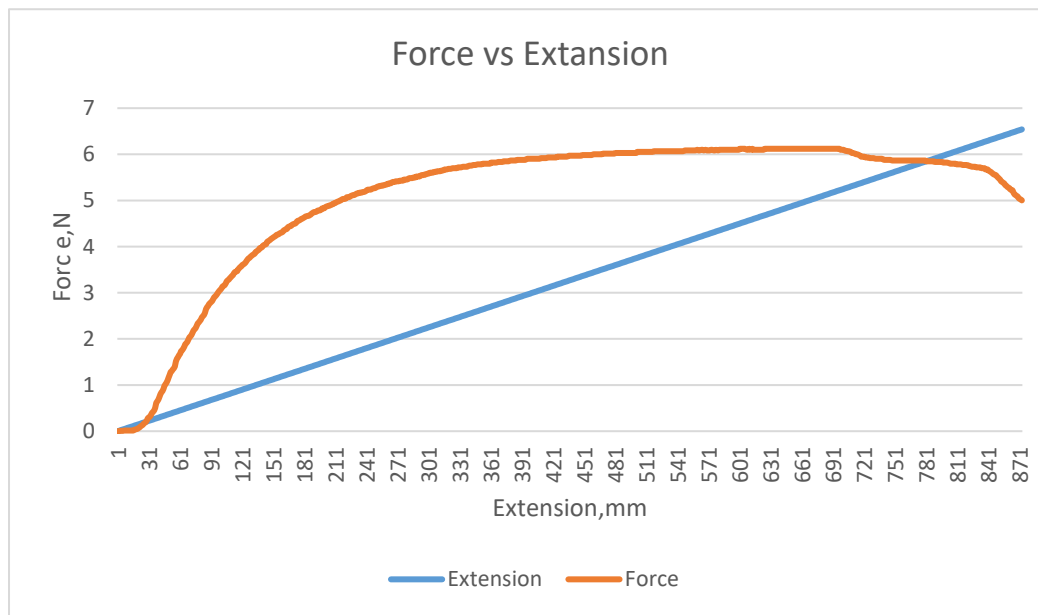
B. Force vs extension of PVA/CCP with 0.5ml of lactic acid blended film.



Summary of the data.

Specimen No	E-modulus, (MPa)	Tensile strength, (MPa)	Elongation at break, (%)
0.5 (R1)	251.2	14.09	44.23
0.5 (R2)	445.7	11.54	10.74
0.5 (R3)	333.6	9.34	10.65
0.5 (R4)	440.2	12.47	14.23
0.5 (R5)	346	8.91	5.62
Mean	363.4	11.27	17.09
Std. Dev.	81.3	2.164	15.48
Median	346	11.54	10.74
Maximum	445.7	14.09	44.23
Minimum	251.2	8.91	5.62

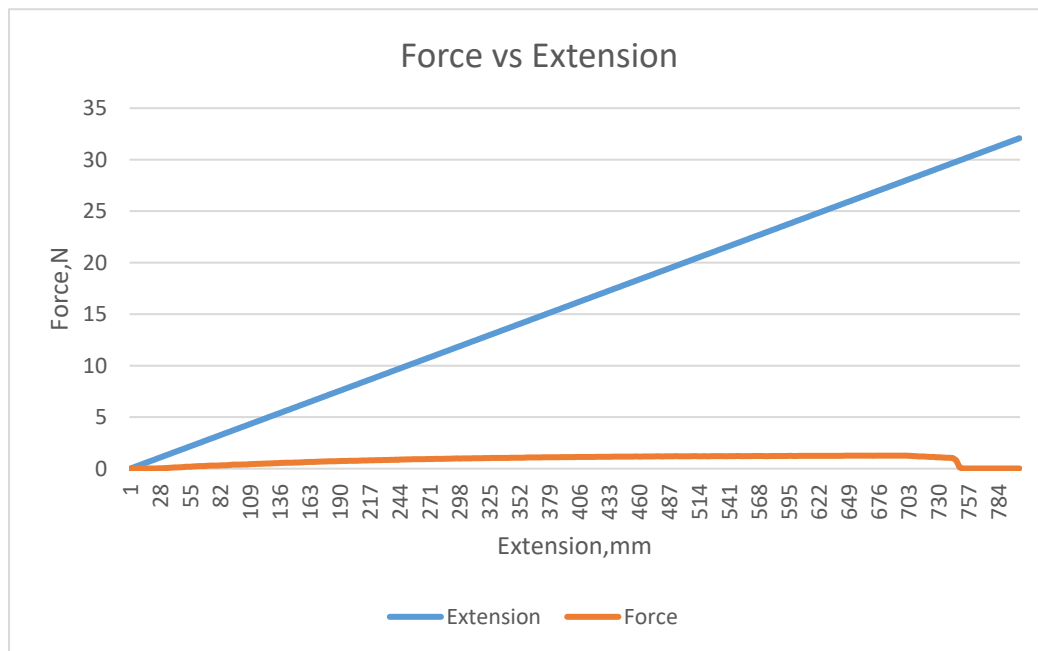
## C. Force vs extension of PVA/CCP with 1.0ml of lactic acid blended film.



Summary of the data.

Specimen No	E-modulus (MPa)	Tensile strength(MPa)	Elongation at break(%)
1.0 (R1)	251.2	14.09	44.23
1.0 (R2)	445.7	11.54	10.74
1.0 (R3)	333.6	9.34	10.65
1.0 (R4)	440.2	12.47	14.23
1.0 (R5)	346	8.91	5.62
Mean	363.4	11.27	17.09
Std. Dev.	81.3	2.164	15.48
Median	346	11.54	10.74
Maximum	445.7	14.09	44.23
Minimum	251.2	8.91	5.62

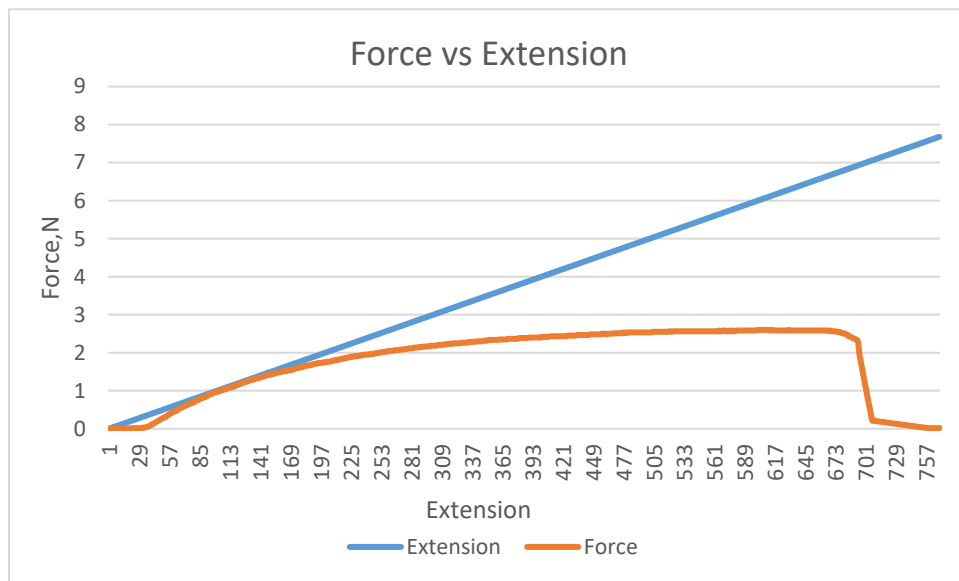
## D. Force vs extension of PVA/CCP with 1.5ml of lactic acid blended film.



Summary of the data.

Specimen No	E-modulus, (MPa)	Tensile strength, (MPa)	Elongation at break, (%)
1.5 (R1)	4.078	1.908	123.4
1.5 (R2)	3.957	1.623	102.8
1.5 (R3)	2.671	1.304	134.3
1.5 (R4)	3.618	1.5	102.8
1.5 (R5)	3.317	1.62	135.7
Mean	3.528	1.591	119.8
Std. Dev.	0.564	0.2196	16.25
Median	3.618	1.62	123.4
Maximum	4.078	1.908	135.7
Minimum	2.671	1.304	102.8

## E. Force vs extension of PVA/CCP with 1.5ml of lactic acid blended film.



Summary of the data.

Specimen No	E-modulus (MPa)	Tensile strength(MPa)	Elongation at break(%)
2.0 (R1)	61.4	4.56	29.54
2.0 (R2)	62.5	4.59	28.77
2.0 (R3)	52	5.26	42.69
2.0 (R4)	98.4	6.27	25.82
2.0 (R5)	68.5	4.56	32.62
Mean	68.6	5.05	31.89
Std. Dev.	17.71	0.746	6.51
Median	62.5	4.59	29.54
Maximum	98.4	6.27	42.69
Minimum	52	4.56	25.82