

**PHYSICAL AND MECHANICAL PROPERTIES OF CORN STARCH BLENDED  
WITH POLYPROPYLENE FOR FUTURE AUTOMOTIVE INTERIOR PARTS**

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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

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WITH POLYPROPYLENE FOR FUTURE AUTOMOTIVE INTERIOR PARTS**

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**A report submitted  
In fulfilment of the requirements for the degree of  
Bachelor of Mechanical Engineering (BMCG)**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

## DECLARATION

I declare that this project report entitled “Mechanical and morphological properties of corn starch blended with polypropylene for future automotive parts” is the result of my own work except as cited in the references.

Signature : .....  
Name : Rahman Bin Latuwo  
Date : .....

## APPROVAL

I hereby declare that I have read this project report and in my opinion this project is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : .....

Supervisor's Name : Dr. Mohd Rody Bin Mohamad Zin

Date : .....

## **DEDICATION**

To my beloved mother and father

## ABSTRACT

Biodegradable that originated from renewable natural resources are currently being paid attention and focused as alternative to synthetic polymer. Therefore, numerous effort has been exerted to develop a natural polymer plastic. Among the natural polymer, starch is one of the interests. Starch inherently biodegradable that can be degraded by others living microorganisms. Unfortunately, there are some solid confinements for applications and creating starch-based polymer because of the absence of a water obstruction property and poor mechanical properties since starch is inherently brittle caused by high intermolecular forces. A variety of corn-starch/polypropylene (PP) compounds with different corn-starch content to improve their mechanical properties were processed by compression using motorise hydraulic moulding test press. The purpose of this study was to obtain the best and appropriate concentration of the corn-starch and PP on mechanical properties. Investigation on their characteristics and mechanical properties were done using universal testing machine instron-8872, durometer test, and electronic densimeter respectively. The addition of corn-starch content to PP reduced the tensile strength and the elongation, but the Young's modulus or stiffness of material increased. The presence of high starch content adversely affected the tensile strength of corn-starch/PP blends. However, the density increases with the addition of corn-starch on PP. For the shore hardness, it was found that the PP with 10 wt.% corn-starch content had the highest hardness.

## ABSTRAK

*Bahan biodegradasi yang diperbuat daripada sumber semula jadi yang boleh diperbaharui kini sedang diperhatikan dan diteliti sebagai alternatif kepada polimer sintetik. Oleh itu, pelbagai usaha telah dilakukan untuk membangunkan plastik polimer semulajadi. Antara polimer semulajadi yang menjadi perhatian adalah tepung kanji. Tepung kanji secara semula jadi boleh terbiodegradasi oleh tindakbalas mikroorganisma. Malangnya, tepung kanji ini mempunyai beberapa limitasi dan batasan untuk ianya dibangunkan dan digunakan. Ini kerana sifatnya yang tidak menghalang penyerapan air dan sifat mekanikal yang lemah kerana kanji secara semulajadi adalah rapuh disebabkan oleh daya intermolekul yang tinggi. Pelbagai sebatian kanji jagung / polipropilena (PP) dengan pelbagai kandungan kanji jagung untuk meningkatkan sifat mekanikal telah disediakan dengan menggunakan mesin acuan hidraulik motor secara kaedah mampatan. Tujuan kajian ini adalah untuk mendapatkan kandungan kanji jagung dan PP yang terbaik dan tepat pada sifat mekanikalnya. Kajian terhadap ciri-ciri bahan dan sifat mekanikal telah dijalankan dengan menggunakan mesin Ujian Universal Instron-8872, ujian durometer, dan densimeter elektronik. Penambahan kandungan kanji jagung terhadap PP dapat mengurangkan kekuatan tegangan dan pemanjangan serta meningkatkan modulus atau kekauan bahan. Kewujudan kandungan kanji yang tinggi mempunyai kesan buruk kepada kekuatan tegangan terhadap campuran kanji jagung / PP. Walau bagaimanapun, ketumpatan bertambah dengan penambahan kandungan kanji jagung pada PP. Untuk kekerasan, PP dengan 10% kandungan kanji jagung mempunyai kekerasan yang tertinggi.*

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## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	i
<b>ABSTRAK</b>	ii
<b>ACKNOWLEDGEMENTS</b>	iii
<b>TABLE OF CONTENT</b>	iv
<b>LIST OF TABLES</b>	vi
<b>LIST OF FIGURES</b>	vii
<b>LIST OF ABBREVIATIONS</b>	ix
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	1
1.1 Background	1
1.2 Problem Statement	1
1.3 Objective	2
1.4 Scope	2
<b>2. LITERATURE REVIEW</b>	3
2.1 Introduction	3
2.2 Starch	4
2.2.1 Chemistry of Starch	4
2.2.1.1 Amylose	5
2.2.1.2 Amylopectin	6
2.2.2 Starch Structure	6
2.2.3 Thermoplastic Starch	7
2.2.3.1 Starch Plasticization	7
2.2.4 Water Absorption on Starch	9
2.2.5 Effect of Starch on Mechanical Properties	9

2.3 Polypropylene	12
2.3.1 Effect of PP on Mechanical Properties	13
2.4 Morphological studies	14
<b>3. METHODOLOGY</b>	<b>16</b>
3.1 Introduction	16
3.2 Material	18
3.3 Preparation of Polypropylene	19
3.4 Preparation of CS/PP Films	21
3.4 Characterization	24
3.4.1 Tensile Test	24
3.4.2 Shore Hardness	27
3.4.3 Density	28
<b>4. RESULTS AND DISCUSSION</b>	<b>29</b>
4.1 Introduction	29
4.2 Results	29
4.2.1 Corn-Starch and PP Sample	29
4.2.2 Shore Hardness	31
4.2.3 Tensile Test	32
4.2.3.1 Stress-strain curve for each sample for 3 specimen	32
4.2.3.2 Average Tensile Properties of CS/PP	35
4.2.4 Density	38
<b>5. CONCLUSION AND RECOMMENDATIONS</b>	<b>39</b>
5.1 Conclusion	39
5.2 Recommendation	39
<b>REFERENCE</b>	<b>40</b>
<b>APPENDICES</b>	<b>44</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
Table 2.1	Average TS analysis result of LDPE and LDPE-g-MA/starch composites	11
Table 2.2	Mechanical Properties of Starch and PP blends	13
Table 3.1	Details of Films Preparation	16
Table 4.1	Tensile Properties of CS/PP composite	37
Table 4.2	Density of CS/PP composite	38

## LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	Structure of the amylose polymer	4
Figure 2.2	Structure of the amylopectin polymer	5
Figure 2.3	Helical Structure of the $\alpha$ - amylose molecule	6
Figure 2.4	Starch Structure	7
Figure 2.5	Relationship between $T_g$ of TPS and plasticizer content and type	8
Figure 2.6	TS of PVA/CS ratio (with 20% formaldehyde)	9
Figure 2.7	Elongation at break (%) of PV/CS ratio (with 20% formaldehyde)	10
Figure 2.8	Effects of DS on the TS and elongation at break (%) of the MCS/PVA films	10
Figure 2.9	Effect of potato starch and agar content on the TS and E	11
Figure 2.10	Molecular Structure of Polypropylene (PP)	12
Figure 2.11	Tensile Strength (MPa), Flexural Strength (MPa), and %Strain of PS/PP/PP-g-Ma blend	14
Figure 2.12	SEM images of agar/PS with concentration agar from 0%, 15% and 30%	15
Figure 3.1	Flow chart of methodology	17
Figure 3.2	Corn Starch	18
Figure 3.3	Polypropylene	18
Figure 3.4	Pulveriser-High Manganese Grinding Bowl	19
Figure 3.5	Bowl	19
Figure 3.6	Sieve Shaker	20
Figure 3.7	Polypropylene Waste	20
Figure 3.8	Polypropylene Powder (500 $\mu$ m)	20
Figure 3.9	Motorise Hydraulic Moulding Test Press	21

Figure 3.10	Weighing Scale Digital	21
Figure 3.11	Transparent plastic box	22
Figure 3.12	Blended Weighted Material	22
Figure 3.13	Ball Mill	23
Figure 3.14	Mould	23
Figure 3.15	Pre-Heat, Compress and Cooling Process	24
Figure 3.16	Hydraulic Compress H-Frame 10 Ton Enerpac	24
Figure 3.17	Universal Testing Machine Instron-8872	25
Figure 3.18	Specimen for Tensile Test	25
Figure 3.19	Tensile test (specimen rupture)	26
Figure 3.20	Tensile Designations (stress-strain curve)	27
Figure 3.21	Durometer Test (in shore D)	27
Figure 3.22	Electronic Densimeter	28
Figure 4.1	Polypropylene (PP) 100% ratio films	29
Figure 4.2	Corn-starch 10% and PP 90% ratio films	30
Figure 4.3	Corn-starch 20% and PP 80% ratio films	30
Figure 4.4	Corn-starch 30% and PP 70% ratio films	30
Figure 4.5	Corn-starch 40% and PP 60% ratio films	31
Figure 4.6	Effect of Corn-starch and PP content on Hardness (in shore D)	32
Figure 4.7	Stress-Strain Graph for 100% PP	33
Figure 4.8	Stress-Strain Graph for Corn-starch 10% and 90% PP	33
Figure 4.9	Stress-Strain Graph for Corn-starch 20% and 80% PP	34
Figure 4.10	Stress-Strain Graph for Corn-starch 30% and 70% PP	34
Figure 4.11	Stress-Strain Graph for Corn-starch 40% and 60% PP	35
Figure 4.12	Effect of corn-starch and polypropylene content on tensile properties (Ultimate Tensile Strength and Young's Modulus)	36
Figure 4.13	Effect of corn-starch and polypropylene content on elongation	36

## LIST OF ABBREVIATIONS

CS	Corn Starch
PP	Polypropylene
PVA	Polyvinyl Alcohol
SEM	Scanning Electron Microscope
TS	Tensile Strength
EB	Elongation at Break
ASTM	American Society for Testing and Materials
LDPE	Low-Density Polyethylene
LDPE-g-MA	Low-Density Polyethylene Grafted Maleic Anhydride
MFI	Melt Flow Index
MEO	Mentha Pulegium
MCS	Methylated-Cornstarch
DS	Degree of Substitution
PBAT	Poly(butylene adipate-co-terephthalate)
PC	Polycarbonate
PS	Polystyrene
PVC	Polyvinylchloride
PP-g-MA	Polypropylene Grafted Maleic Anhydride
SG	Specific Gravity
RD	Relative Density

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Mechanical properties of a material including tensile strength, elongation at break and at yields, and elasticity or stiffness are characteristics which involve an application of the load reaction and are usually achieved by tensile testing. When the tensile test have been done stress-strain graph can be obtained by using the universal testing machine. American society for testing and materials were used as a standard reference when performing the test.

Due to the non-degradability and potential environmental risk of synthetic polymers many efforts were made to produce eco-friendly alternatives to plastic inventions. Starch is one of the options as a biodegradable polymer. Unfortunately, the mechanical properties of starch are poor. Due to the poor mechanical characteristics, starch and plastic were tested to improve mechanical properties. Therefore, corn-starch and polypropylene (PP) were blend together with a various content to determine the optimum corn-starch content in PP (up to 40%) that can produce good mechanical properties as regards of tensile strength, elongation at break, young's modulus, shore hardness and density.

### 1.2 Problem Statement

Various endeavours were made to create polymers based on starch in order to avoid wasted overuse of petrochemical resources, reduce the natural impact and searching for more applications. Regardless, wide applications have been compelled because of the lack of water barrier property and destitute mechanical properties, such as film fragility brought by high sub-atomic strengths. However, the incorporation of other additives may improve the mechanical properties of starch film. Therefore, the focus of this research is to blend corn-starch with polypropylene (PP) in order to discover the most excellent mechanical properties for future automotive parts.

### **1.3 Objective**

The objective of this research is:

- i. To determine the optimal ratio of corn-starch blended with polypropylene (PP).
- ii. To investigate the effect of corn-starch additives at various polypropylene (PP) ratios on physical and mechanical properties of the resulting blends.

### **1.4 Scope**

In order to achieve the objective, the scopes are arranged as shown below.

- i. Polypropylene are blended with different volume percentage of corn-starch content that is 10%, 20%, 30%, and 40% and 100% polypropylene ratio.
- ii. Testing film specimen by Tensile Strength (TS) and Elongation at break (EB) with American Society for Testing and Materials (ASTM D-638) as reference.
- iii. Testing film specimen Hardness with ASTM D-2240 as reference.
- iv. Testing film specimen density by using electronic densimeter.



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Over the past century, development in science and technology, amount of synthetic polymer has been grown rapidly for various industrial uses and applications. Synthetic polymer material has been produced widely every year. Around 140 million tons are produced annually from synthetic polymers (Katarzyna Leja\*, 2010). The synthetic polymers are derived from petroleum oil, and are considered to be non-degradables. The use of synthetic polymer materials, causes severe environmental issues such as plastic waste as it is not biodegradable polymers. A non-biodegradable cannot be disposal by others living organisms and its take a thousand years to degrade. One of the alternatives to dispose those plastics is by burning them for energy production. However, this simply actions can cause air pollution which is produced carbon dioxide and other gases.

Therefore, there is a lot of research and effort focus on natural polymer to protect petroleum resources as an alternative to synthetic polymer, to reduce the environmental problem and find additional applications (Lu, Xiao and Xu, 2009). Starch in one of interest in the natural polymer. Starch as an alternative to petroleum resources has been considered as it is regenerated by photosynthesis in plants from carbon dioxide and water (Lu, Xiao and Xu, 2009). Starch inherently biodegradable that can be degraded by others living microorganisms such as bacteria, fungi and algae. They will also brake down the polymer chain through non-enzymatic approaches including chemical hydrolysis (Gross and Kalra, 2002). Moreover, it is a low costs, non-toxicity, abundance of renewable resources and high production (Li *et al.*, 2015). Unfortunately, due to the lack of a water barrier property and poor mechanical properties of starch caused by high intermolecular forces, there are certain restrictions on the use of starch-based polymers. Therefore, several attempts have been made to blend starch with other additive polymer to improve and enhance the mechanical properties such as starch blended with polyvinyl alcohol (PVA) that possesses excellent mechanical properties (Azahari, Othman and Ismail, 2011).

## 2.2 Starch

Starch is a natural polymer which occurs extensively in plants. It is produced throughout photosynthesis and functions as the principal polysaccharide reserve material. Pure starch is a white powder, tasteless and odourless that cannot be soluble in water without blood or alcohol. Potatoes, corn, and rice are the primary bodies used in production. In all the plants. In all of those plants, starch is deposited within the form of complicated structure that known as granules, with various shapes and size relying on the botanical origin (Chandra and Rustgi, 1998). In superior plant tissues, starch is synthesised through a chain of complex enzyme reactions by means of glucose-1-phosphate (Ai and Jane, 2017). In amyloplastic storage starch is made as discrete granules with separate morphologies for a single plant life ranging from spherical, oval, ogival, or elongated to flat, in diameter of sub-microns of over 100 $\mu\text{m}$ , lenticular or polyhedral (Bertoft, 2017). The characteristics of the gelatinisation temperatures, viscosity and clarity of pastas, gelling ability, and retrogradation rate (relating to syneresis), dependent on the botanical source.

### 2.2.1 Chemistry of Starch

Starch granules consist almost totally of major polysaccharides, specifically amylose and amylopectin. Both of these polymers are composed of repeating units of  $\alpha$ -D-glucose. The major element of maximum starches is amylopectin and it is commonly made up 70% of the polysaccharide content. There are various methods used to separate the amylose from the amylopectin that precipitates the amylose as a 1-butanol complex, a process that Schoch developed in 1942. The structure of amylose and amylopectin are shown below in Figure 1.2 and Figure 1.3, respectively.

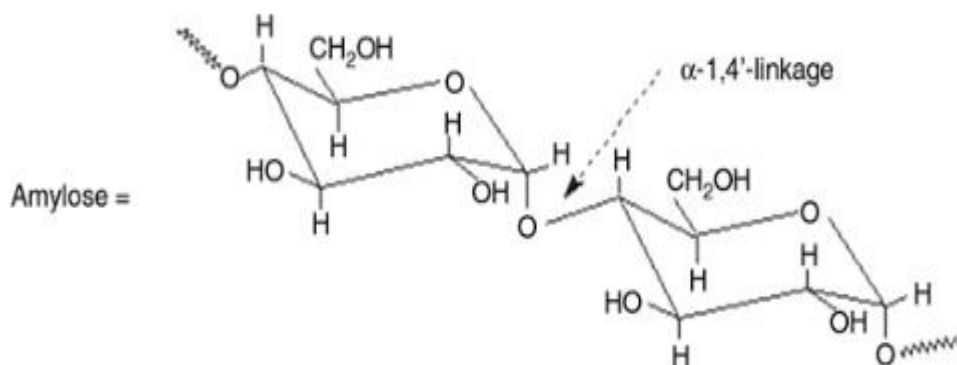


Figure 2.1 Structure of the amylose polymer.(Lu, Xiao and Xu, 2009)

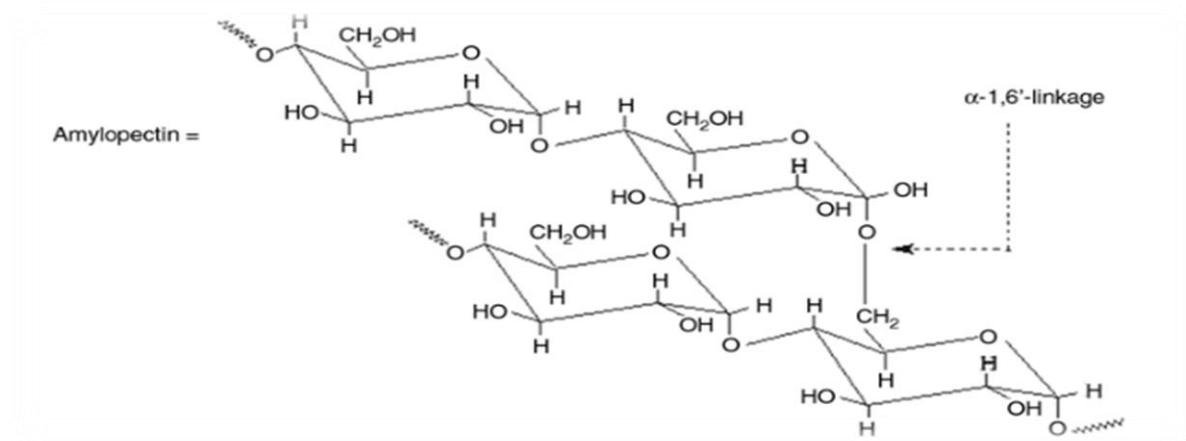


Figure 2.2 Structure of the amylopectin polymer. (Lu, Xiao, & Xu 2009)

### 2.2.1.1 Amylose

Amylose are a linear macromolecule containing glucose units with  $\alpha$ -1,4 linkages. Each macromolecule has one lower end and one non-lower end. However, enzyme investigations have shown that the amylose molecule has a small degree of  $\alpha$ -1,6-connections as with amylopectin. (Chen, 1990). The polymer strands of  $\alpha$ -amylose in starch undertake a helical structure as shown in figure 2.3 similar that found in nucleic acids. Ordinary chain lengths for  $\alpha$ -amylose units are about 1,000 monomer units. Amylose is very essential in plant energy storage where it is less easily digested than amylopectin, but due to its helical structure it takes up much less area compared to amylopectin. In the end, it is the recommended starch for plant storage. It accounts for approximately 30% of the starch stored in plants, but the percentage varies by species and variations (Wang *et al.*, 2017). Amylose content in starch are different with the different type of starch. For instance, corn starch is about 28% amylose and potato starch contains about 23% amylose. Common starches usually contain between 17 and 28% amylose and high amylose starches, which contain between 45 and 69% amylose (W. Banks, C. T. Greenwood, 1973).

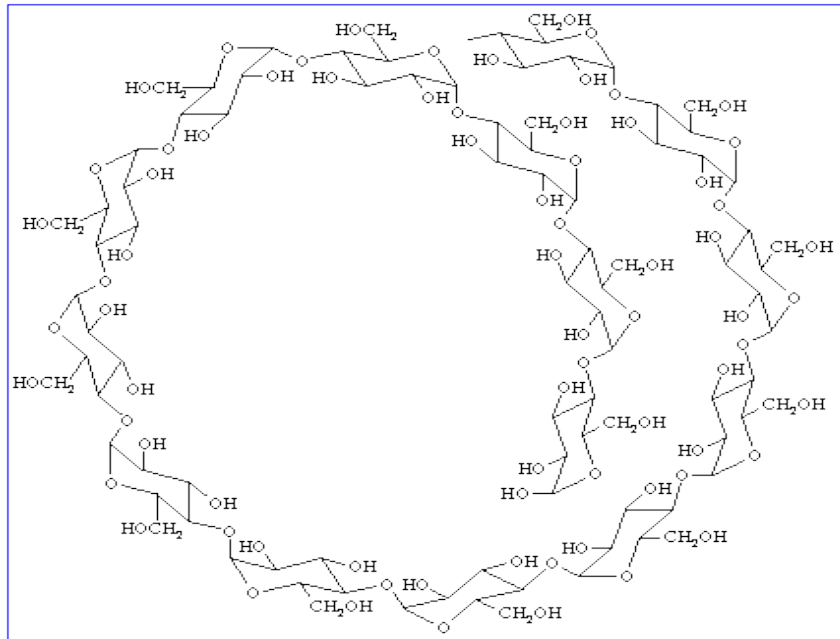


Figure 2.3 Helical Structure of the  $\alpha$ - amylose molecule

### 2.2.1.2 Amylopectin

Amylopectin is a water-soluble polysaccharide that is a branched  $\alpha$ -glucose unit component found in plants (Green, Blankenhorn and Hart, 1975). The amylopectin D-glucopyranose is linked especially with  $\alpha$ -1,4 bonds with 5-6 percent of  $\alpha$ -1,6 bands at branches where the average duration of the branching chain is 20-25 units but the common duration of the chain of the high amylose corn amylopectin is higher than 30 units (C.T. Greenwood, 1966). This glucose unit is a soluble molecule that can become more rapidly degraded because there are numerous end points where enzymes can be attached. By contrast, amylose consists of just a few  $\alpha$ -1,6 or perhaps none that produces amylose which is hydrolysed very slowly. It is however more dense and insoluble.

### 2.2.2 Starch Structure

The amylose and amylopectin starch molecule is composed of a glucose Monomer as a semi-crystalline polymer. Every starch molecules have two important functional groups, namely the -OH groups which have susceptible replacement reactions and high water associations which cause much of thermoplastic starch water absorption problem. Furthermore the chain vulnerable C-O-C bond. By its reaction-OH-group, changes in many properties can be made by mixing and keeping them untouched or melted and combined with the suitable molecular polymer (K. Oduola, 2015).

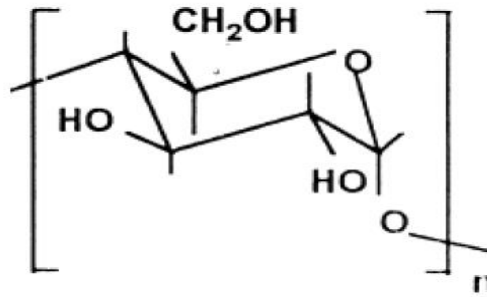


Figure 2.4 Starch Structure (K. Oduola, 2015)

### 2.2.3 Thermoplastic Starch

Thermoplastic starch is a plasticized starch that processes the crystalline starch structure to form an amorphous thermoplastic starch with heat and pressure. Starch plasticized is a starch mixed in with other plasticizers or additives that make processing possible. The processing of thermoplastic starch usually involves an irreversible transitional order-disorder known as gelatinisation. Disruption of molecular within the starch granules is called the gelatinisation of starch and this process is affected by the interactions between starch and water. Most processing of starch usually involves heating of water and several different additives, such as sugar and salt, to control gelatinisation in food industries and glycerol as a plasticizer for applications in biodegradable plastics (Halley *et al.*, 2007). Process of gelatinisation breaks up the granule structure of starch by disrupting the hydrogen bonding within adjacent glucose molecules and destroys its crystallinity (K. Oduola, 2015). Thermoplastic starch is a poor elongation and high tensile strength properties. It is due to the impact of the retro gradation on the mechanical properties that increase the tensile strength and decrease the elongation in breaks. Due to water absorption in the thermoplastic matrix, the polymer chain can be realigned by the occurrence of -OH groups (Nafchi *et al.*, 2013).

#### 2.2.3.1 Starch Plasticization

Native starch has no thermoplastic properties without any addition of plasticizers such as water or glycerol. Product made from native starch is easily broken up into a fragment when dried in the environment, due to strong intermolecular linkages of hydrogen within the macromolecular chain of amylose and amylopectin. The high temperature and heating of the native starch melt and flow readily, allowing its utilization as an extruding, injection or blowing material similar to most traditional synthetic thermoplastic polymers. (Ma, Yu and Wang, 2007). Plasticizers attract water molecules around them and reduce the inter-molecular interactions between the starch molecules so that native starch increases their

flexibility. This process of breakage by softening the form and enhancing the mobility of the macromolecular chains, resulting in a decrease in processing temperature, is called starch plasticization. (Zhang and Curtis, 2012).

Usually used plasticizers for thermoplastic starch are water, glycerol, fructose, sugar, glycols, formamide, urea, ethanolamine, and ethylene bisformamide. These chemicals are smaller and hydrophilic in their molecular size. The most common and affective plasticizers are traditionally water and glycerol. (Zhang and Curtis, 2012).

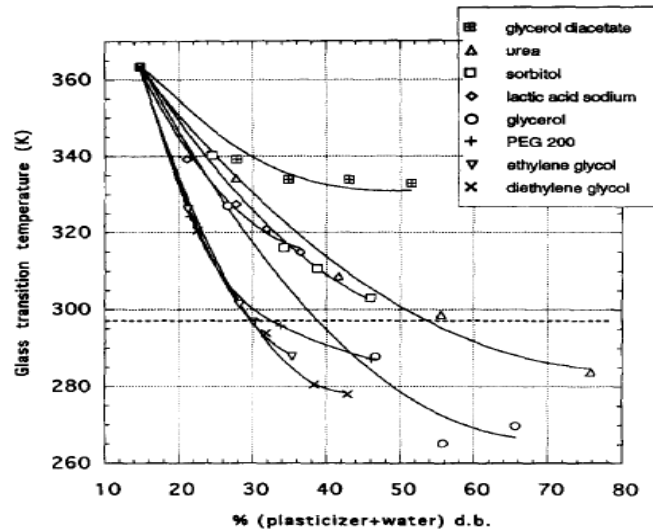


Figure 2.5 Relationship between  $T_g$  of TPS and plasticizer content and type (Lourdin *et al.*, 1997).

A minimum of 20% glycerol or any other appropriate plasticizer is required to successfully plasticize starch. The properties of thermoplastic starch can reduce the strength of the stress, Young's modulus and glass transition temperature ( $T_g$ ) with increasing plasticizer quantity and increase the elongation at breakage and gas permeability. Thermoplastic starch film with 25% glycerol shows the greatest tensile strength and the best elasticity modulus. (Pyshpadass, Marx and Hanna, 2008). In general, the increasing of the concentration of plasticizer will result in a lower  $T_g$ . It is because more plasticizer groups are available to bond with starch, hence increasing starch chain mobility but the intensity of this decrease is dependent on the nature of the plasticizer used (Lourdin *et al.*, 1997).

#### 2.2.4 Water Absorption on Starch

Water absorption capacity and degradability are the most important properties for biodegradable materials. The material water absorbed allowed the microorganisms to grow and utilize the material as an energy source (Guohua *et al.*, 2006). The absorption of composite film into the polymer matrix immediately proportional to the amount of starch. In another sentence, water absorption will be increased in low-density polyethylene (LDPE) by increasing its starch content material. The hydrophilicity of starch and the ionic nature of the hydroxyl starch classes is responsible for water absorption. If the composite has lower mechanical properties the water absorption is high (Oromiehie, Lari and Rabiee, 2013).

#### 2.2.5 Effect of Starch on Mechanical Properties

Starch have an interest to develop a biodegradable polymer composite. However, starch blended with other polymer resulting in different mechanical properties although the biodegradable starch has poor mechanical properties.

Maize starch and PVA (Polyvinyl Alcohol) combination films were made using a different ratio of starch and PVA casting solution method, followed by an investigation of the mechanical effects on the biodegradability of the film tested by the effects of gamma radiation. The result from the test show that tensile strength of the film decreased accordingly as the amount of CS increased. Elongation at break also continuously decreased as the amount of CS increased. TS and break elongation because of the amorphous nature of the starch that increases fragility and leads to a lower TS of the film. The PVA / CS dosage for  $\gamma$ -radiation, increases the TS value. The radiation cross-link reaction of TS of PVA / CS films was improved (Shafik, Majeed and Kamil, 2014).

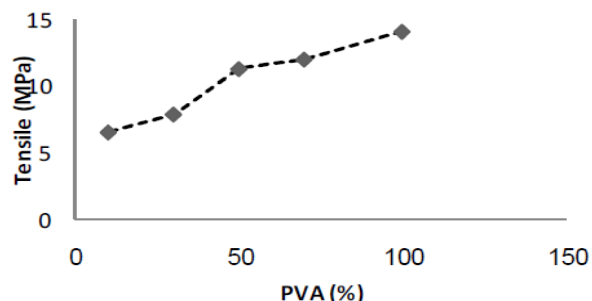


Figure 2.6 TS of PVA/CS ratio (with 20% formaldehyde) (Shafik, Majeed and Kamil, 2014)

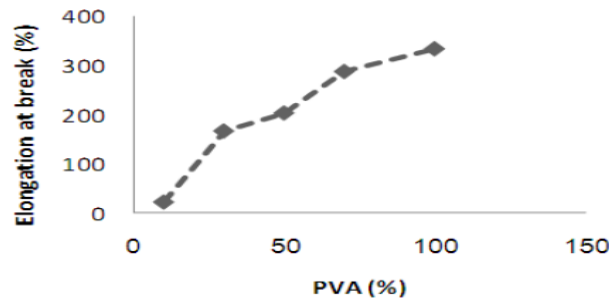


Figure 2.7 Elongation at break (%) of PV/CS ratio (with 20% formaldehyde) (Shafik, Majeed and Kamil, 2014)

Corn starch films were prepared by mixing methylated-cornstarch (MCS) with PVA and then the mechanical properties have been investigated. From the result, it was found that MCS/PVA film had higher water resistance other than the CS/PVA film. Also, the TS and elongation at break of MCS/PVA film continuously increased as the degree of substitution (DS) increased. Figure 2.8 illustrates that the TS is increased dramatically by increasing DS from 0.096 to 0.275 and TS from 0.275 to 0.864, with DS further increased from 0.275 to 0.863. (Guohua *et al.*, 2006)

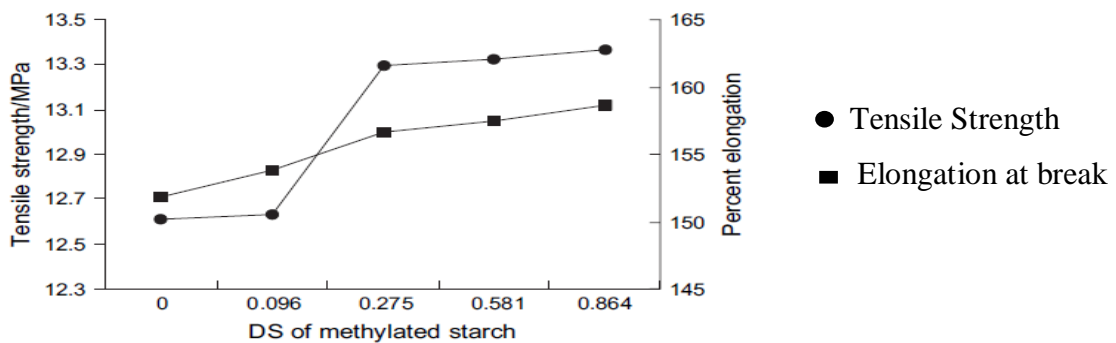


Figure 2.8 Effects of DS on the TS and elongation at break (%) of the MCS/PVA films (Guohua *et al.*, 2006)

Potato starch films was prepared by mixing with low density polyethylene (LDPE) and low density polyethylene grafted maleic anhydride (LDPE-g-MA). Starch content varied between 0 and 30% and mechanical properties was tested on the films by following ASTM Method D-638 (ASTM D638, 2015). As the amounts of starch increased the TS and elongation at break decreased. Definitely the tensile properties depend highly on the starch content on the films (Gupta, Sharma and Kumar, 2008).