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TEKNOLOGI
PETRONAS

FINAL YEAR PROJECT: PROJECT DISSERTATION

**A STUDY OF PHYSICAL PROPERTIES & SHOCK ABSORPTION ABILITIES OF
STARCH POLYMER FOAM AS CUSHIONING MATERIAL FOR PACKAGING**

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A project dissertation submitted in fulfilment of requirement for the
Bachelor of Engineering (Hons)
Mechanical Engineering
JANUARY 2016

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CERTIFICATION

CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

.....

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ABSTRACT

This project involved in producing starch polymer foam to be used as cushioning material for packaging. To produce the starch polymer foam; starch, PVA, urea, citric acid, and dionised water are the selected materials. Water amount and, drying and curing process were the variables that were being manipulated to produce the best foam of cushioning material for packaging. After several changes of the variables, the best ratio of starch:pva: citric acid is 1:1:4. The amount of water used is 10 ml/gram of starch/PVA weight. The best foaming process was done at a speed of 1500rpm for 40minutes. Drying process was done at 70 °C for 24 hours, and after that, the curing process was done at 100 °C for 1hour to produce closed cell foam. The two best samples, open cell and closed cell foams produced were cut to 6cm x 6cm x 0.5cm. The density the foams were measured and then subjected to weight drop destructive test. The test was done by placing the foams on the top of a piece of mirror, and a piece of weight is dropped on the foams with increasing height. The starch foams were compared with polyurethane and polystyrene foams in terms of the minimum height that can cause the mirror to break. 0.05kg, 0.1kg and 0.2kg weights were used to be dropped on the top of the foam with increasing height until the mirror breaks. The results shows that starch closed cell foam absorb the highest impact force followed by polystyrene foam, starch open cell foam and polyurethane foam.

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CHAPTER 1: INTRODUCTION

1.1 Background Study

The packaging industry is growing broadly as it is linked to the growth of world's economy. Packaging has become an essential industry across wide range of industries like healthcare, food and drink, furniture, modern gadget and as well as in other industrial sectors. In 2009, the global packaging industry has turned over around \$564 billion with the sales of packaging containers only [1]. However, the markets of the packaging industries are relying upon the petroleum industries for the raw materials. The traders or retailers have to cope with the price fluctuations of raw material, depending on the supply and demand of their business.

Plastic, which is also called polymer, has been a very important material in packaging industries. It can be found everywhere in our modern world in many variety of products. However, most of the polymer is well known for its contribution to the environmental problem due to disposal method of plastic are very limited. Incineration of plastic may generate toxic air pollution and recycling plastic is expensive and cost very large energy usage. Therefore, biodegradable plastic development and researches have been stimulated due to public concern about the environmental problem caused by the plastic. [2]

Biodegradable polymers can be derived from two sources; petroleum resources and renewable material resources. Polymer that is derived from renewable material can be divided into two classes; natural polymer and bacterial polymer [3].

Plastic foams are often used as cushioning materials for packaging because of its lightweight properties and shock absorption abilities. The most common polymer foam cushioning materials are made up of polystyrene, polyurethane, polyethylene and polypropylene. There are two major types of foams which are open cell and closed cell. Open cell foam allow gases and liquids travel freely through the foam cells, while a closed cell only allowed the gases and liquids to diffuse through the very small boundaries between the foam cells. [4]

Starch is an inexpensive, natural and renewable raw material that can be processed into a polymer. To produce starch polymer, the starch has to be plasticised with plasticizing agent such as urea. Plastic products containing starch are considered biodegradable because starch easily degrades into simpler compounds that can be metabolized by microorganisms

such as fungi, bacteria and yeast [5]. The extruded starch polymer foam was patented by Ivan Tomka in 1996. Since that, several of researches have been made to study the capabilities and properties of starch polymer foam to replace the petroleum based polymer foam.

1.2 Problem Statement

1. Lacks of information about the formulation and fabrication process of starch polymer foam.
2. The shock and impact force absorption ability of the starch polymer foam is unknown due to lack of study in that particular area.

1.3 Objectives

The main objectives of the study are:

1. To formulate and fabricate starch polymer foam as cushioning material for packaging.
2. To test the shock and impact force absorption ability of starch polymer foam and compare with existing cushioning material foam.

1.4 Scope of Study

In this project, starch polymer foam was formulated and fabricated into a cushioning material for packaging. The starch foams will be tested and compared with the existing cushioning materials (polyurethane and polystyrene).

The parametric comparison studies will focus more on:

1. Physical properties
2. Shock absorption abilities.

Other factors such as production cost, tensile properties, chemical properties, thermo graphic analysis (TGA) data and water resistivity properties is not being studied in this project.

1.5 Project Significance

The demand for renewable based polymer is increasing but most of the renewable sources based polymers are not meeting the performance benchmark set by the petroleum based polymer. Therefore, this project will study the ability of the starch as natural polymer foam to replace the existing petroleum based polymer foam.

CHAPTER 2: LITERATURE REVIEW AND THEORY

2.1 Starch Polymer as Packaging Material

Biodegradable polymer or biopolymer is often classified according to its method of production. These are the three most common productions of biopolymers [2]:

- Polymers that are directly extracted from natural materials mainly plants such as starch, cellulose and protein.
- Polymers that are produced by chemical synthesis from renewable monomers.
- Polymers produced by microorganisms or genetically transformed bacteria.

Referring to the first point, starch is also considered as biodegradable polymer. There are many advantages of using starch polymer as packaging material because of its low cost and it is abundantly available. Moreover, because of its thermoplastic properties, which can be process when it is being heated, starch polymer can be molded into desired shape. Furthermore, it is colourless when it is processed into plastic sheet so it can used to wrap fruits, vegetable and snacks.

However, starch itself is vulnerable against moisture and also low in mechanical properties. For that reason, starch has to be mixed with other biodegradable material to make a nanocomposite material to improve its mechanical properties and protection against moisture. Below are some materials that are usually used to be mixed with starch [6]:

- i. Polyvinyl alcohol (PVA)
- ii. Polylactide (PLA)
- iii. Polycaprolactone (PCL)
- iv. Poly(butylene succinate)
- v. Poly(hydroxybutyrate)

According to Vroman et. al., starch/PVA combination is the best because of their compatibility which can highly increase the mechanical properties, elongation and processability. However, increasing the amount of PVA will reduce the rate of degradation of the polymer.

2.2 Material Selection of Starch Polymer Foam

Starch

Starch is a carbohydrate consisting of a massive amount of glucose units connected by glycosidic bonds. There are two types of molecules in the starch which are linear and helical amylose and the branched amylopectin. Starch polymer is very well known for its biodegradability, renewability and low cost material [7].

Different type of starch, such as tapioca, potato, corn and wheat starch have different mechanical properties. Stasiak et. al. has done a study of mechanical properties of native maize, wheat starch and potato starches. In their study, they have proven that different type of starch has different compressibility and density [8].

Distilled water

Pure starch itself is poor in mechanical properties, processability and dimensional stability for its end products. To improve the properties of starch, some physical and chemical modifications of starch have to be made by mixing the starch with other polymers, or with plasticizers and other additives. There are a lot of hydroxyl groups on starch chains, two secondary hydroxyl groups at C-2 and C-3 of each glucose residue, and one primary hydroxyl group at C-6 when it is not linked [9]. The existence of hydroxyl groups in the starch opens up the potential of the starch to have reaction with water and alcohols, so, starch can be oxidized and reduced, and may participate in formation of hydrogen bonds either ether or ester.

Distilled water can be used as the modifying agent because of the existence of hydroxyl group in starch chains which allow water molecules to modify the chains of starch polymer. Moreover, distilled water also able to perform as blowing agent for the starch because when water evaporated, it will release steam to expand and reduce the density of the foam [10]. Therefore, the amount of water is a very important thing in the production of starch polymer foam because it can change the properties of the foam.

Polyvinyl alcohol (PVA)

Shafik et. al. (2014) has proved that addition of PVA into starch reduces the brittle nature of starch and increases the tensile properties [9]. Poor water resistivity of starch polymer is one of the major disadvantages of the material. Although the tensile strength may be rather high, but it becomes too fragile after absorbing water. Therefore, to increase the water resistivity of starch, it must be mixed with PVA which has good water resistivity, excellent film forming and high thermal stability [11].

Based on the study done by Shafik et. al., blend ratio of corn starch and PVA affected the tensile strength and degradability of the polymer. As the amount of corn starch increased, the tensile strength decrease accordingly. Below is the graph shows the effect of different ratio of starch-PVA on tensile strength [12]:

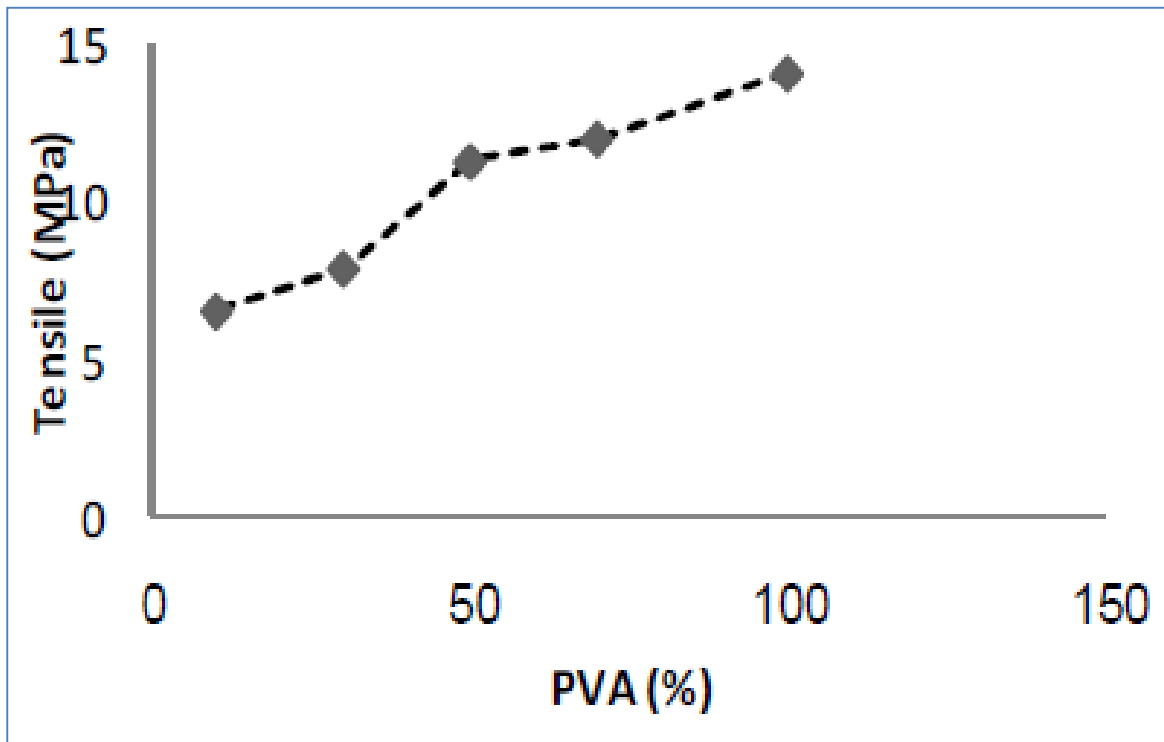


Figure 1: Effect of PVA/CS ratio on Tensile strength [12]

On the other hand, Shafik et. al. has also done the study on the effect of different PVA-corn starch ratio on Soil Burial Test. The test is done by burying the starch-PVA polymer in the same soil condition and in the same period. The result shows that as the amount of corn starch increase, the weight loss percentage increase. Therefore, as the amount of corn starch increase the rate of degradation of the polymer increase. Below is the graph shows the effect of different ratio of starch-PVA on degradability or weight loss after Soil Burial Test [12]:

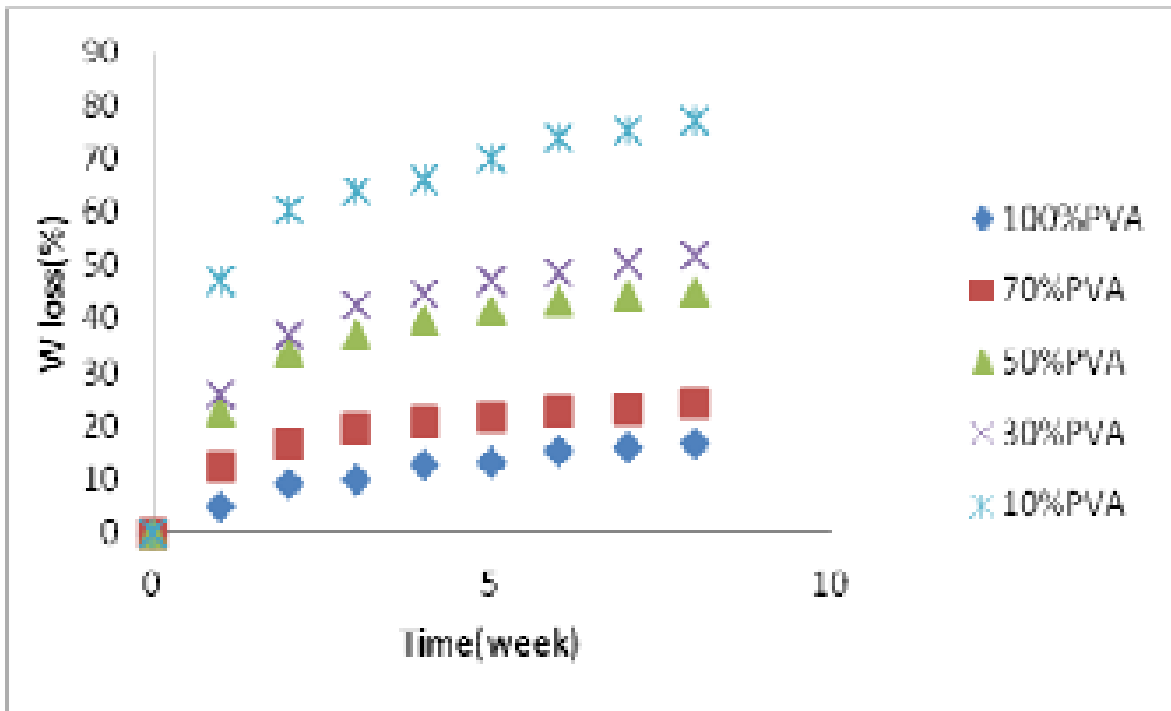


Figure 2: Weight loss of PVA/CS (with 20% formaldehyde) films after buried in soil for 8 weeks [12]

Citric acid

Mixing with water only cannot make the starch usable and comparable with existing cushioning foam in terms of its mechanical properties and physical properties. Therefore, citric acid should be added into the formula to increase the elongation at break. Citric acid has polysaccharides containing hydroxyl groups that have the possibility to be cross-linking by poly-functional carboxylic acid. Therefore, this will slightly increase its rigidity and brittleness due to the cross linking reaction. Moreover, by reacting citric acid with the starch, the molecular weight of the starch will be reduced. As a result, the diffusion rate and permeability of the polymer will be increased [13].

According to Park et. al., addition of citric acid can increase the elongation of the starch polymer. To prove this, Park et. al. has conducted experiments by making different mixture of starch polymer and test their tensile properties of the starch. Below are the graphs showing the result of his experiments:

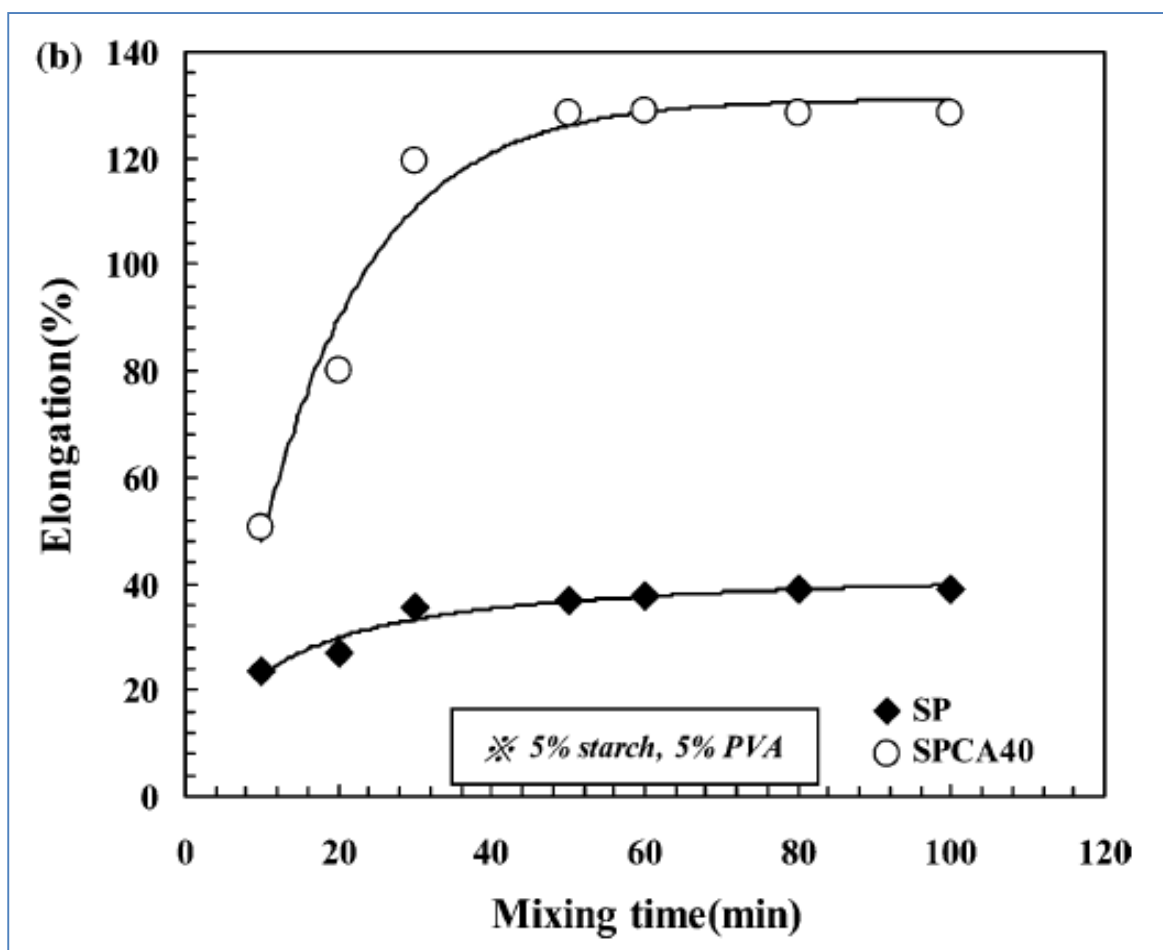


Figure 3: Elongation (%E) of starch/PVA blend film adding with/without additive. Note that, SPCA40 = Starch polymer with 40% of citric acid (weight based), SP = Starch polymer [8]

The starch polymer with addition of citric acid has shown increment of elongation (%) compared to without any additives.

However, it also affected the degree of swelling for the starch. [11]. Degree of swelling is the consequence of interaction between a solvent and a matrix. When a cross-linked polymer kept in a good solvent, it swells rather than dissolve. Swelling degree define the change of dimension of polymer. The higher the degree of swelling, the better the properties of the polymer [11].

2.3 Fabrication of Starch Polymer

Preparation of starch polymer mixture

Shafik et. al. prepared the starch/PVA polymer by solutions casting method. The films were prepared from different weight percentage ratios of both CS and PVA with a fixed formaldehyde (plasticizer) ratio about 20%. The preparation steps can be summarized as below:

A mixture of 100 ml of deionised water and 3 ml of glycerine was prepared. Citric acid and PVA were weighted for suitable ratios, and then mixed with the water-glycerol mixture by a shearing mixer at 500 rpm for 2 hours to have good homogeneity for the mixture. The temperature of the mixture was raised to 80 °C during the mixing stage. 20% weight percentage of plasticizer was added to the mixture. Then the temperature of the mixture was raised up to 95 °C during the mixing stage for 4 hours [12].

Preparation of polymer films

Some of the previous researches use glass plate or petri dish as the mold for the polymer. Chopra et. al. prepared the polymer film by pouring the mixture into the petri dish and allowed the polymer film to dry in oven for 24 hour at 50°C. After 24 hours of drying, the fully dried films were peeled off from the petri plates [7].

Shafik et. al. prepared the polymer film by pouring the mixture on waxed glass plates as a mold of dimensions 10 × 10 cm² for casting the blend sheets. The wax was used to prevent the composite sheets to stick with the mold. The mold was then being put in an oven at 50 °C for 6 hours for drying process, and then the temperature was raised up to 80 °C for 1

hour for cross-linking process to occur. The sheets were pulled from the molds and then they were cut in desirable shapes for the tests.

2.4 Shock Absorption Ability of Cushioning Material Foam

The most important information that needs to be considered when choosing cushioning material for packaging is the shock absorption ability or impact dissipation of the foam. The main function of cushioning is to reduce the deceleration of a dropped product when it hits the ground. The flexibility of the foam can determine the deceleration rate of the falling object and determine the shock absorption ability of the foam when the packaged is dropped hit on the ground. The information of impact dissipation of the foam can determine the maximum drop height of the packaging [14].

To determine the shock absorption ability of foam, finding the cushion curve of the foam is the common practice. Cushion curve is the graphical illustration of a foam ability to limit the transmission of shock to its product which is called G level or fragility. The more fragile a product, the lesser the G level it can receive. The cushion curve is very specific to each material, density and thickness of the foam. By constructing the cushion curve, we can visually tell how many G's will be transmitted for a given drop height, cushion thickness and static loading. The picture below shows one example of cushion curve:

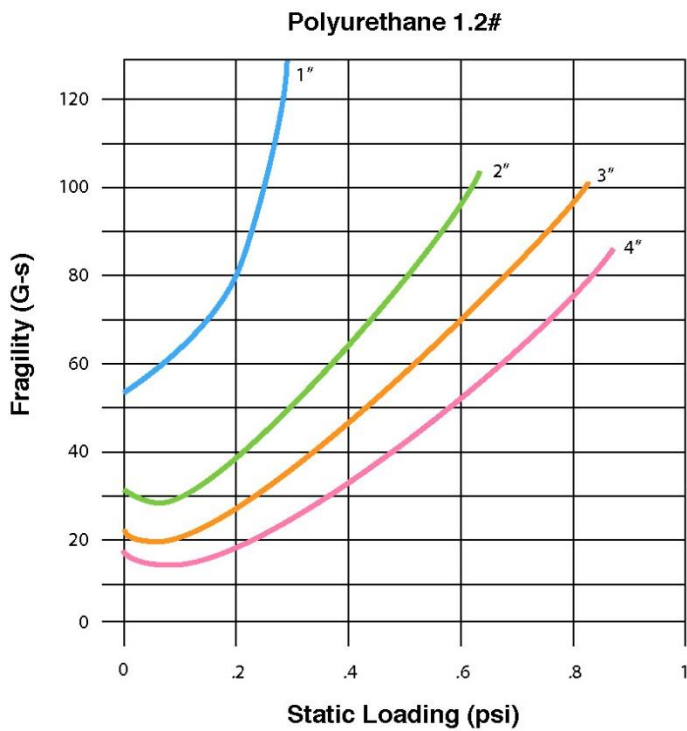


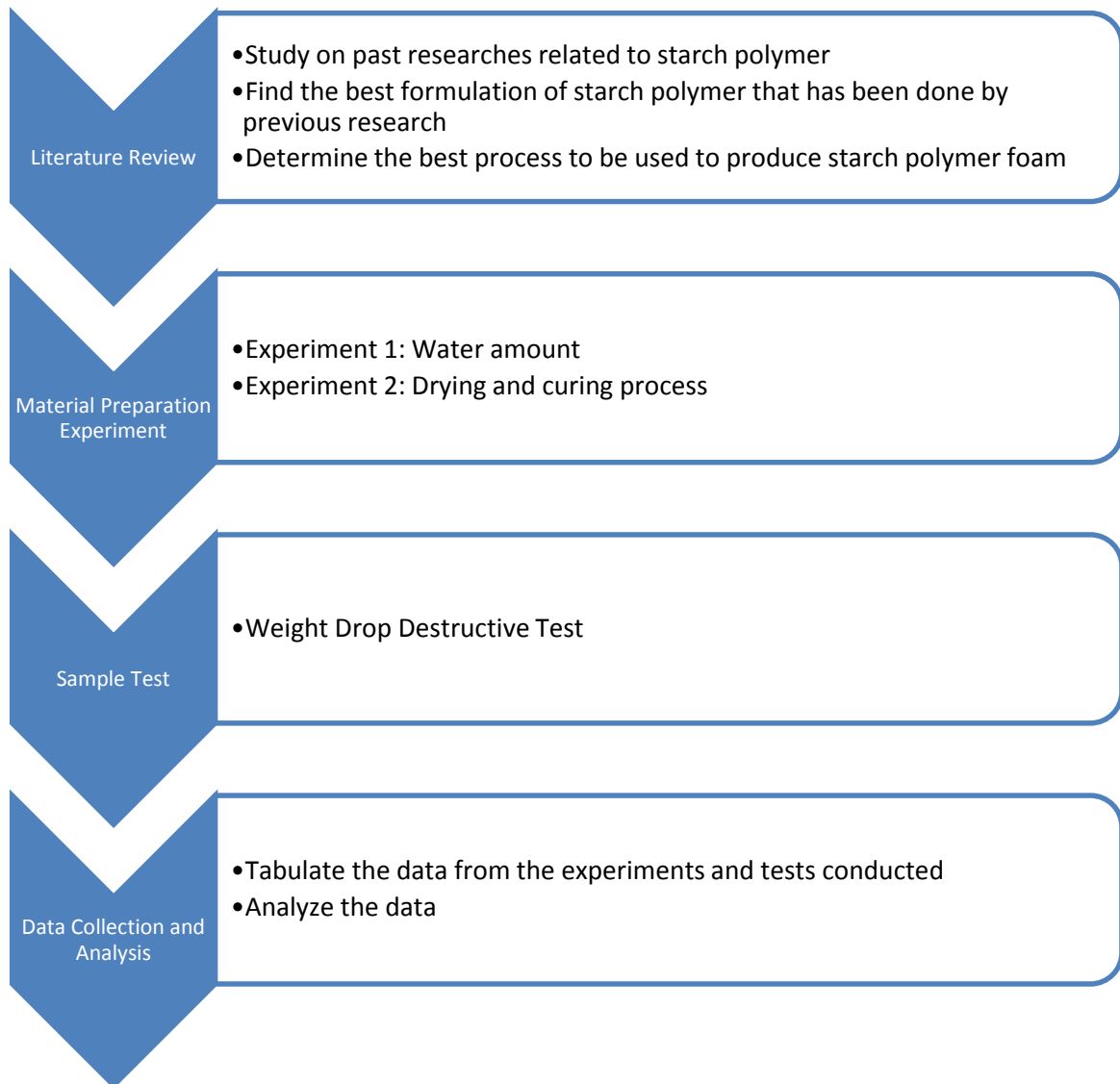
Figure 4: Polyurethane cushion curve

To generate this cushion curve, there is an outline in ASTM D1596. However, to generate a full set of cushion curves for each type of foam would require on the order of 10 500 sample drops and over 175 hours of test time.

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart

Figure below shows the project flow chart of this project:



3.2 Tools and Equipments

Most of these tools and equipments are available at block 4, UTP. Table below shows the equipment used and their functions:

Tools and Equipments	Functions
<p data-bbox="188 510 580 544">Hotplate with magnetic stirrer</p> 	<p data-bbox="809 510 1337 580">To mix the starch polymer mixture in an elevated temperature up to 90°C.</p>
<p data-bbox="188 1243 427 1276">Mechanical stirrer</p> 	<p data-bbox="809 1243 1374 1312">To foam the starch polymer mixture at high speed.</p>

Oven



To dry and cure the starch polymer foam.

Plastic container



To be used as mold for the foam.

Electronic balance



To weigh all the materials used and to weigh the mass of the foam after being dried and cured.

3.3 Formulation and Fabrication

The proposed formulation to be used in the fabrication of starch polymer foam was as below:

Material Selection

Substance	Default Composition
Starch	5g
Polyvinyl alcohol (PVA)	5g
Citric acid	20g
Urea	3g
Dionised water	50ml + 100ml

Table 1: Starch polymer formulation

The ratio of starch:pva:citric acid is 1:1:4, and the amount of urea is 10% and the amount of dionised water is 5ml/g of weight of starch, PVA and citric acid.

The proposed fabrication process of starch polymer foam was as below:

Fabrication Process

A. Mixing

1. PVA is poured into flask together with 100 ml of distilled water and the flask is immersed in water bath of 90°C and is stirred with magnetic stirrer in 300rpm until the PVA is completely dissolve.
2. Starch and urea is mixed with 50 ml of distilled water in a beaker.
3. The starch-urea mixture is poured in the flask.
4. The mixture is stirred with magnetic stirrer for 45 minutes at 300rpm.
5. The gel-like mixture is cooled to room temperature before start foaming it.

B. Foaming

1. Citric acid is added into the cooled gel-like mixture.
2. The mixture is stirred with mechanical stirrer at 1000rpm for 45 minutes and the mixture is foamed after that process.

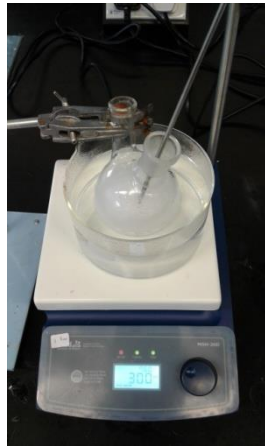
C. Drying and curing

1. The foamed mixture is poured into the mold.
2. The mold is put inside the oven of 100°C and is left to be cured for 4 hours.

Figure below shows the summary of the main steps and processes involved in producing starch polymer foam:



a) Weighing the materials



b) Mixing the materials



c) Foaming the mixture



d) Drying and curing in oven

Figure 5: Summary of sample preparation

However, there were many problems arose during the fabrication process. Thus, some modifications in formulation and fabrication process were done in order to get the best starch polymer foam. Modification was done in water amount, drying and curing process and type of starch.

Water amount variation

Aim :

To find the best amount of water for the formation of starch polymer foam.

Hypothesis :

The larger the amount of water, the longer the drying process needs to be done. Besides, excessive amount of water may lead to failure in the foaming process because excessive amount of water leads to the foam to become too soft.

Procedure :

The starch polymer foam fabrication process is done by changing the amount of water as tabulated below.

p/s : PVA water + starch-urea water

Composition 1	Composition 2
100ml + 50ml	50ml + 50ml

Table 2: Water amount variation

Drying and Curing Process

Aim :

To find the optimum time and temperature for drying and curing process using oven.

Hypothesis :

The higher the foaming speed and longer the foaming process, may result in higher the increment of the volume, thus lowering the density of the foam. Therefore, to produce open cell foam will require higher foaming speed compared to closed cell foam.

Procedure :

In this experiment, the same fabrication process with the best amount of water and optimum speed for foaming process is used. The drying and curing procedure is varied as shown below.

Method 1	Method 2	Method 3
Drying and curing for 4 hours at 120 °C	Drying and curing for 6 hours at 100 °C	Drying for 24 hours at 70 °C Curing for 1 hour at 100 °C

Table 3: Drying curing process

3.4 Weight Drop Destructive Test

To determine the shock absorption ability of the foams, normally ASTM D4168, test standard methods for transmitted shock characteristics of foam in place cushioning material is used. Other than that, in order to determine the cushion curve of the foam, ASTM D1596 is used. However, due to some restriction of time, equipments and machines, the test will be replaced with a weight drop test which is a destructive test. This test was done to compare the performance of different types of foams in terms of their ability to absorb impact force from a free fall weight.

Test Apparatus

1. Mirror (1.0 mm thick)
2. PVC pipe
3. Weight (0.05kg, 0.1kg, 0.2kg)
4. String
5. Pulley
6. Foam (6.0 cm height x 6.0 cm width x 0.5 cm thick)

The foam was cut into pieces of 6.0 cm height x 6.0 cm width x 0.5 cm thick as shown in the table below:





Polyurethane	Starch open cell foam	Polystyrene	Starch closed cell foam
			

Table 4: Foams cut into pieces of 6cm x 6cm x 0.5cm

Test Procedure



Figure 6: Weight drop test apparatus

1. The apparatus was set up as the picture above.
2. At first, the mirror was placed on a flat concrete surface below the PVC pipe.
3. The weight was dropped through the PVC pipe starting at 2.0 cm height from the mirror, and was kept increasing by 2.0 cm until the mirror breaks.
4. The height where the mirror breaks was noted down.
5. The force of impact where the mirror breaks was calculated by the formula of $F=mgh$, where m = mass of the weight, g = gravitational acceleration (9.81 m/s^2), h = height.
6. Step 1-5 were repeated by placing tapioca foam, corn starch foam, polyurethane foam, and polystyrene foam on the top of the mirror.
7. The impact force where the mirror breaks of each foam was compared.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Formulation and Fabrication

Experiment 1: Water amount variation

100ml + 50ml



Figure 7: Top surface of the foam



Figure 8: Bottom of the foam

The bottom of the foam did not dry because of excessive amount of water. This happen because the drying of the foam occur from top to bottom. To produce the best foam, the

moisture level should be very low. In order to dry out all the water, higher drying temperature or longer drying time or lower amount of water need to be taken into consideration.

50ml + 50ml



Figure 9: Top Surface of the foam

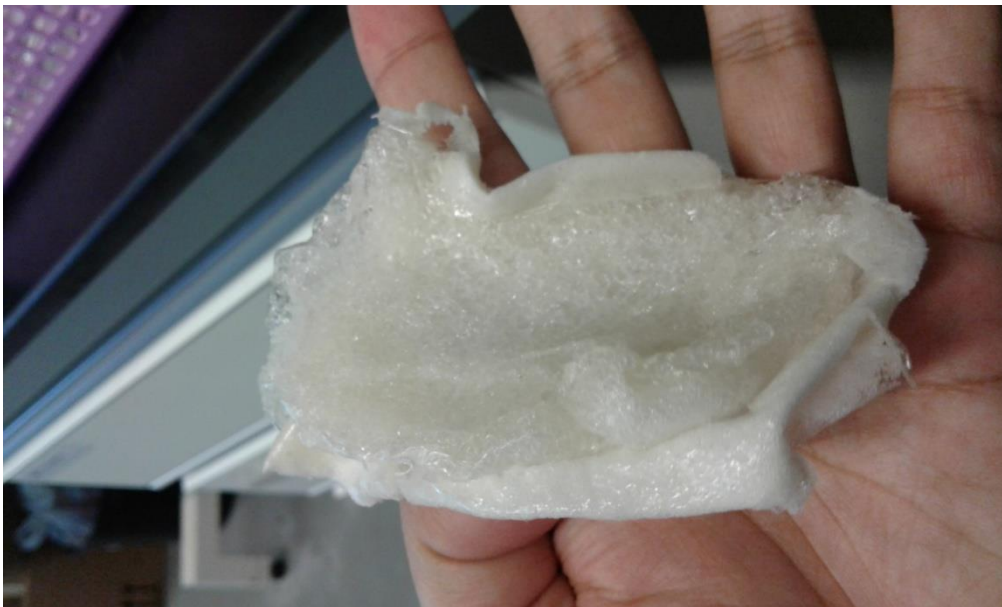


Figure 10: Bottom surface of foam

The bottom of the sample was completely dry but it was not cured enough. Because of that, the sample was quite difficult to be removed from the mold hence, ruining the shape of the foam. However, this sample is the best sample from this experiment. Therefore, the best amount of water to produce starch polymer foam is 10 ml of water per 1g of starch/PVA/citric acid weight.

Experiment 2: Drying and Curing Process Variation

120°C for 4 hours



Figure 11: Foam started to degrade

The sample has an open cell foam properties because of its softness and its big pore size. The sample can be squeezed and it will turn back to its original shape. Moreover, the sample can be easily ejected from the mold because it is fully dried and cured. However, it started to turn into brown colour and it is very fragile. It is too soft, delicate and easily ragged. It is expected that if the temperature was reduced and the time of curing was raised, the foam could be better.

100°C for 6 hours



Figure 12: Foam is soft and delicate

The sample still has the open cell foam properties because of its big pore size and its softness. It can be squeezed and return to its original shape after force was released. The sample can easily be ejected from the mold because it is fully dried and cured. The properties are like memory foam of polyurethane. This is the best starch open cell foam.

70 °C for 24 hours, cure at 100 °C for 1 hour



Figure 13: Sample C3 closed cell foam

With 24 hours drying time at 70°C and curing at 100°C for 1 hour, the closed cell foam is produced. The physical property of the foam is nearly the same as polystyrene foam. The foam produced is rigid foam. The sample is easily ejected from the mold because it has completely dried and cured. This is the best starch closed cell foam.

4.2 Physical Properties and Formulation of the Best Foams Produced

Samples	Closed cell foam	Polystyrene	Open cell foam	Polyurethane
Volume (after being cut)	6.0 cm height x 6.0 cm width x 0.5 cm thick	6.0 cm height x 6.0 cm width x 0.5 cm thick	6.0 cm height x 6.0 cm width x 0.5 cm thick	6.0 cm height x 6.0 cm width x 0.5 cm thick
Average weight (g)	10.827	0.496	2.329	0.716
Density (g/cm)	0.6015	0.0276	0.1294	0.03978
Flexibility	rigid	rigid	flexible	flexible

Table 5: Physical properties and formulation of the best foams produced and existing cushioning material

From the properties of the foams, open cell foam can be compared with polyurethane foam because of its flexibility and low density. While closed cell foam can be compared with polystyrene because of its rigidity.

4.3 Weight Drop Destructive Test

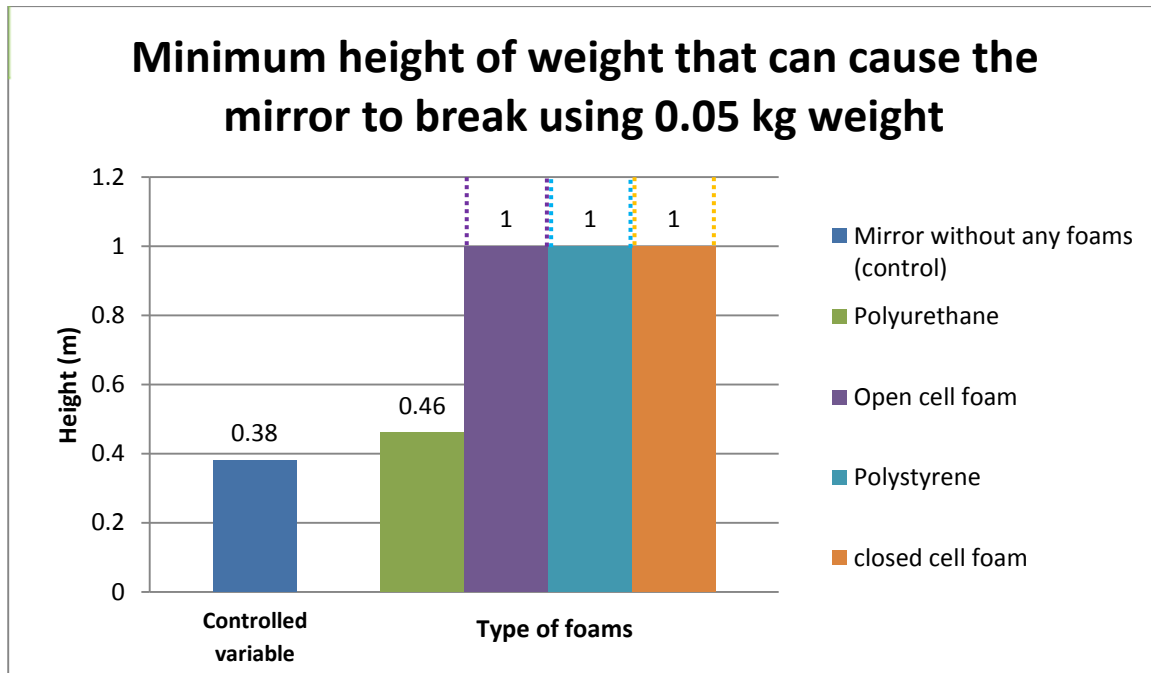


Figure 14: Chart of maximum height where mirror breaks using 0.05kg weight

The chart above shows the maximum height of the weight before it is being dropped and causes the mirror to break. For the control variable, a mirror without any foams are being tested. It shows that, with weight of 0.05 kg, the minimum height of weight that can cause the mirror to break is 0.38m. After polyurethane foam is placed on the top of the mirror, the minimum height of weight that causes the mirror to break increases to 0.46m. It shows that, polyurethane foam was absorbing the impact force because there is some small difference between with foam and without foam. It proved that this test worked. For open cell foam, polystyrene and close cell foam, the weight is not enough to break the mirror within 1.0m of height. Therefore, the weight is increased after that.

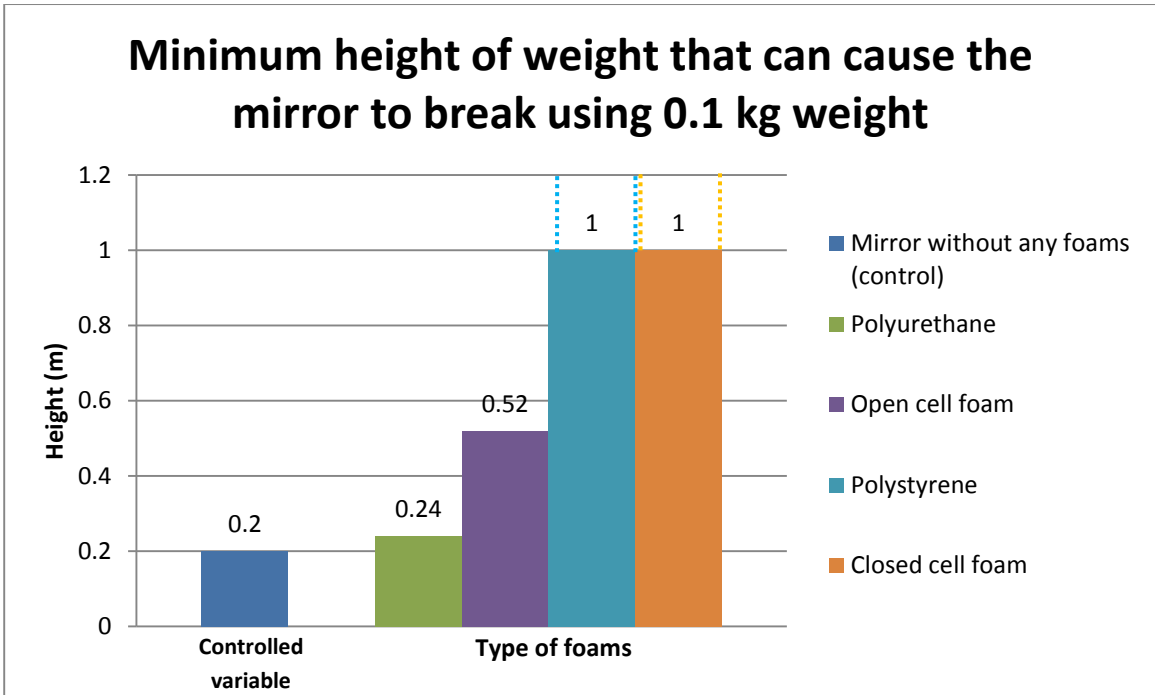


Figure 15: Chart of maximum height where mirror breaks using 0.1kg weight

In this chart, it shows some reduction of height for mirror without foams and the polyurethane foam. This happened due to increasing weight that causes higher impact force. For open cell foam, the mirror broke at the height of 0.52 m. So, it is better than polyurethane foam because it can absorb more impact force.

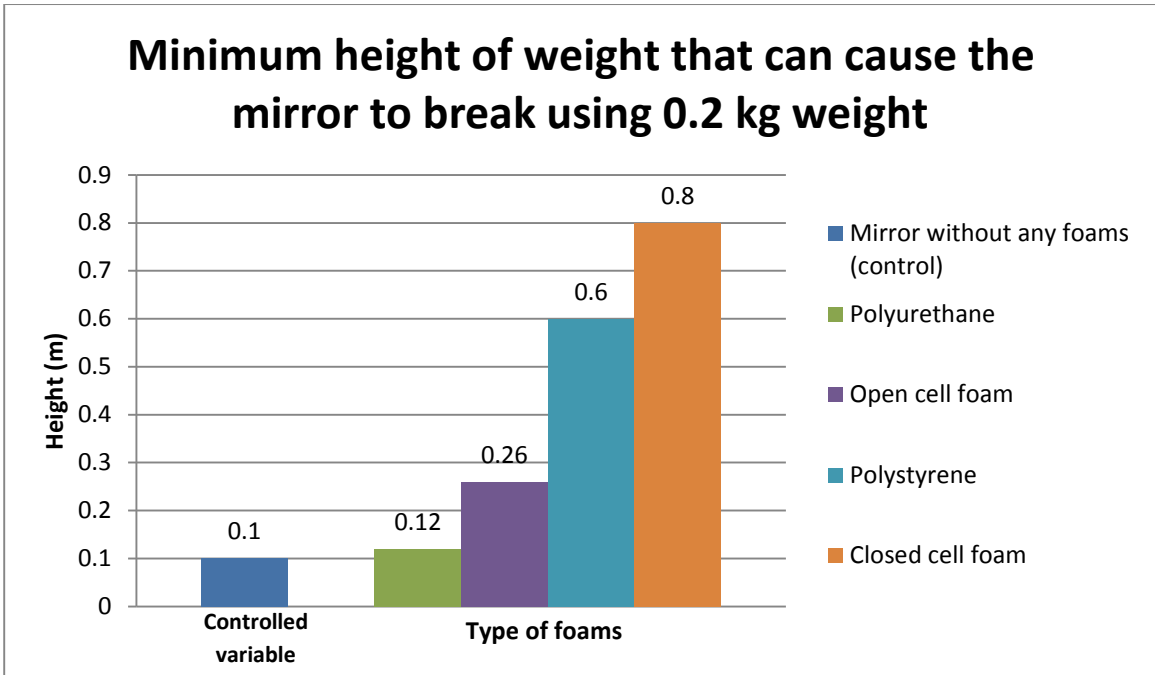


Figure 16: Chart of maximum height where mirror breaks using 0.2kg weight

In this chart of 0.2kg weight, all the mirrors are broken. Closed cell foam has the highest minimum height of weight, thus it prove that it has the most shock absorption ability compared to polystyrene foam.

To calculate the impact force, potential energy formula is used. $F = m.g.h$, where; F = impact force, m =mass of the weight, $g = 9.81\text{m/s}^2$, and h = initial height of weight before being dropped.

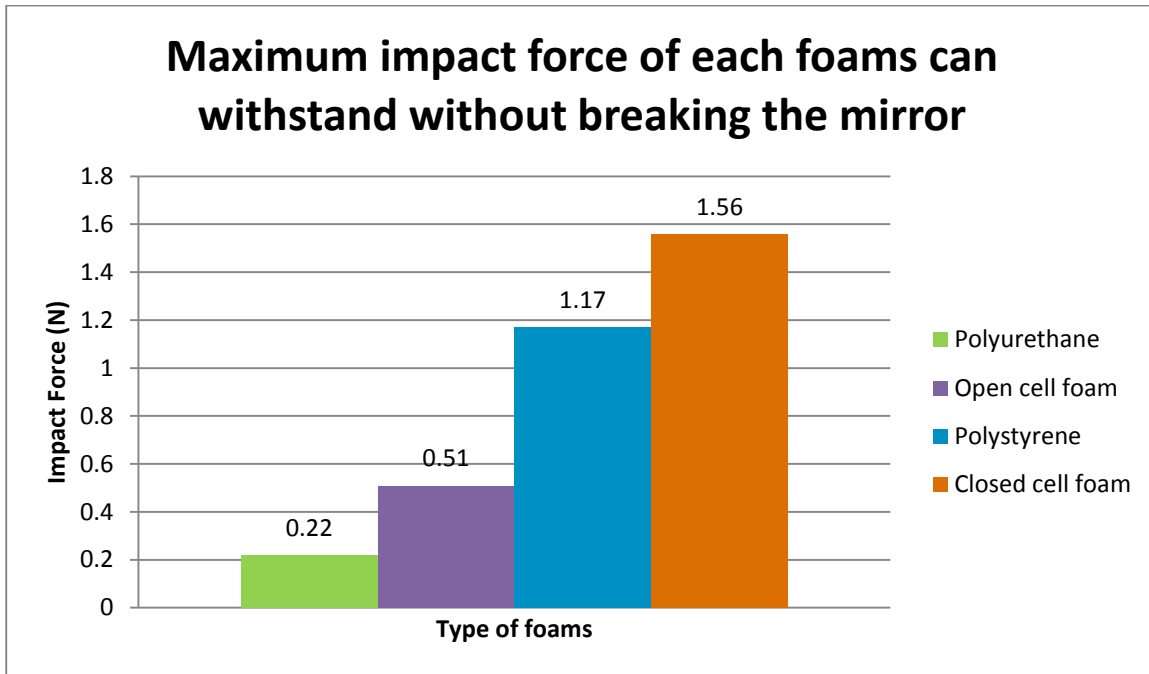


Figure 17: Chart of maximum impact force that each foams can withstand without breaking the mirror

From the graph, closed cell foam can absorb impact force 33.33% higher than polystyrene foam. Open cell foam can absorb impact force 131.8% higher than polyurethane foam.

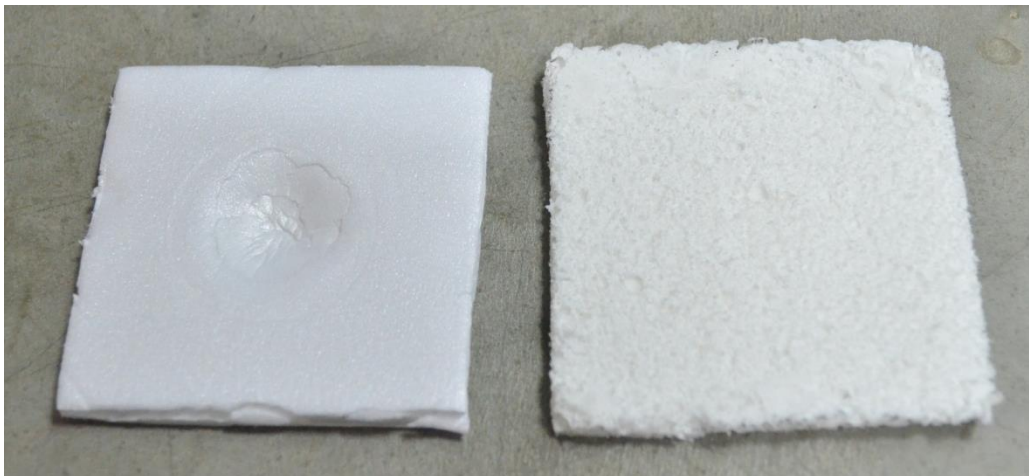


Figure 18: Polystyrene and sample B2 (from left) after the weight drop test

Moreover, from the figure above, polystyrene has defect on the surface while starch closed foam is still flawless. It shows that starch closed foam can withstand repetitive amount of impact compared to polystyrene.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

In conclusion, excessive amount of water can cause the foaming process fail and the foam will no dry perfectly. The best amount of water to produce starch polymer foam is 10 ml of water per 1g of starch/PVA. Different drying and curing process will cause different foam properties. If the foam is dried and cured at 100°C for 6hours, it will produce open cell foam because the water boils at that temperature and cause the steam bubbles to create bigger pores to the foam. If the foam was dried at 70 °C for 24 hours and cured at 100°C for another 1 hour, the foam produced is closed cell foam because the foam is slowly dried. The property of the foam produced is rigid and less flexibility. Therefore, we can say, it is closed cell foam. The best foams produced are comparable with existing cushioning material foams which are polystyrene and polyurethane foams.

From the packaging drop test, starch closed cell foam has higher shock absorption ability compared to polystyrene because it can withstand higher impact force to protect the mirror from breaking. On the other hand, starch open cell foam also has higher shock absorption ability compared to polyurethane foam. Therefore, it prove that both of the starch polymer foam sample is better than existing cushioning material foams in terms of shock absorption ability. However, the disadvantages of both samples are the density is too high compared to polyurethane and polystyrene.

For future study, it is recommended to use the twin screw extruder machine to fabricate the starch polymer foam for easier, short period of time and accurate fabrication process. Besides, it is recommended in the future, to study the properties of foam by changing the variables like amount of urea, foaming speed and time, or addition of other additives to produce higher quality of starch polymer foam. Furthermore, more study needs to be done on how to reduce the density of the starch polymer foam.

On top of that, it is also recommended to do the tensile test to determine its mechanical tensile properties. Furthermore, thermographic analysis can also be done to determine its chemical properties like degradation temperature, moisture content and heat resistivity.

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