PREPARATION OF THERMOPLASTIC CONTAINER VIA THERMOFORMING PROCESS

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UNIVERSITI MALAYSIA PAHANG

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This thesis is submitted as partial fulfilment of the requirements
for the award of the degree of
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To my beloved family members and friends

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ABSTRACT

Thermoforming process is one of the processes used in fabrication of plastic part. Thermoforming process is a process of changing flat thermoplastic sheet to three dimensional shapes. The type of thermoforming process used in this project is vacuum forming. Thermoforming process rarely used in industry of fabrication thermoplastic container. Thermoplastic are plastic that softened and can form any shape using heat and its return to a solid upon cooling. The thermoplastic material type used in this project is Polypropylene (PP). The properties of this (PP) material are economical material, good and resistance to fatigue. Therefore, the main objective of this study to prepare the thermoplastic container by using thermoforming process. In preparation of this thermoplastic container, the design and fabricate the mould is the important process to produce good container. The difference temperature used to identify the suitable temperature used in thermoforming process. The temperature used start with 160^{o}c until 200^{o}c. The result shows the suitable temperature in range 165^{o}c-170^{o}c.

ABSTRAK

Proses Termopembentukan merupakan salah satu proses dalam fabrikasi bahagian plastik. Proses Termopembentukan adalah proses menukar termoplastik rata kepada tiga bentuk dimensi. Jenis proses termopembentukan digunakan dalam projek ini adalah pembentukan berkedap udara. Proses Termopembentukan jarang digunakan dalam industry pembuatan bekas termoplastik fabrikasi. Termoplastik adalah plastik yang lembut dan boleh membentuk apa-apa bentuk menggunakan haba dan kembali kepada pepejal apabila disejukkan. Jenis bahan termoplastik yang digunakan dalam projek ini adalah (PP). Sifat-sifat (PP) ini adalah murah dan beketahanan baik. Oleh itu, objektif utama kajian ini untuk menyediakan bekas termoplastik dengan menggunakan proses termopembentukan. Dalam penyediaan bekas termoplastik, reka bentuk dan fabrikasi acuan adalah proses penting untuk menghasilkan bekas yang baik. Suhu perbezaan digunakan untuk mengenal pasti suhu yang sesuai digunakan dalam proses termopembentukan. Suhu yang digunakan bermula dengan 160^{0}c sehingga 200^{0}c. Hasil daripadakajian yang dijalankan telah menunjukkan suhu yang sesuai ialah di antara 165^{0}c-170^{0}c.

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LIST OF ABBREVIATIONS

PP	Polypropylene
Catia	Computer Aided Three-dimensional Interactive Application
ABS	Acrylonitrile butadiene styrene
ASTM	American Society for Testing Materials
CNC	Computer Numerical Control
G-code	G programming language.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, plastic getting more popular among the industry of fabrication container compare to other material because of their properties that are light weight, high wear resistance and easy to fabricate. Most important characteristic of the plastic is a low production cost and this make plastic become more valuable.

Thermoplastic are plastic that softened and can form any shape using heat and it returns to a solid upon cooling. Thermoplastic also called a thermo softening plastic. The most thermoplastic criteria are having high molecular weight. The example of some thermoplastic type is polypropylene, polycarbonate and acrylic.

The thermoplastic material type used in this project is Polypropylene (PP). The properties of this (PP) material are economical material, good resistance to fatigue and also has a high melting point of temperature. The most important, polypropylene (PP) is recyclable and has number 5 as its identification. Polypropylene (PP) is useful for such diverse products as reusable plastic food containers, microwave and dishwasher safe plastic containers.

Thermoforming is the process that used in industry for plastic part. Thermoforming process is a process of changing flat thermoplastic sheet to three dimensional shapes. There are three types of thermoforming process which are vacuum forming, pressure forming and match die forming.

Therefore, the design consideration for thermoplastic container is also important. The design of mould containers needs a practical design so that the container has a good quality, value and the part can be vacuum during thermoforming. The type of material used for mould also may affect the thermoforming process.

1.2 PROBLEM STATEMENT

Nowadays, the plastic container cannot last longer and can be easily leak because of the unpractical design and material used.

Thermoforming process is the process that rarely used in the fabrication of the container compare to injection moulding. The Injection moulding process most uses for fabrication of thermoplastic material, but has high cost of tooling and equipment compare to thermoforming process.

This project built to study about the suitable of PP thermoplastic material as a thermoplastic container fabricates via thermoforming process. Plus, to investigate the benefits of using thermoforming process in preparing thermoplastic container.

1.3 OBJECTIVE

The objectives of this project are:

1. To design and fabricate the mould of the container.
2. To fabricate Polypropylene (PP) thermoplastic container using thermoforming process.
3. To analyse polypropylene container product fabricated via thermoforming process.

1.4 SCOP OF PROJECT

This project used thermoplastic material such as polypropylene (PP) for the preparation of thermoplastic container. This is because the ability of this material which has good impact resistance, high melting point, and cost effective plastic for thermoforming process.

The mould was designed using Catia V5 2013 software and simulated the g-code to generate in CNC milling machine. Based on this software the part can be machined by simulating it to make sure no mistake during machine the part.

The thermoforming process for preparing of PP thermoplastic container as main of this research. Thermoforming process has a low of tooling cost and equipment cost compare to blow moulding and injection moulding. Thermoforming process is selected for fabrication of PP thermoplastic container because thermoforming has less thermal stress compares to injection moulding and compression moulding. Thermoforming process also used in both production operations either high and low volume.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The main role of this chapter is to provide a review of past research and guidelines efforts related to thermoforming process and thermoplastic of polypropylene material. The polypropylene material used over the industry for replacement of expansive grand plastic. This information is important because it will lead to this study applicability till complete. In this research, it's also the best way to guide and face the problem encountered during the completion of this study.

2.2 THERMOPLASTIC

A thermoplastic, or thermosoftening plastic, is a plastic material, a polymer that becomes pliable or mouldable above a specific temperature and solidifies upon cooling [1]. The process that usually used for changing the shape of thermoplastic are injection moulding, compression moulding, and thermoforming process. There are lot of thermoplastic that usually used in the industry nowadays such as; polycarbonate, polypropylene, polyethylene, polystyrene, ABS and more. But, the focus of thermoplastic needs to study is Polypropylene (PP) sheet type.

2.2.1 Polypropylene (PP)

Polypropylene (PP), also known as polypropylene, is a thermoplastic polymer used in a wide variety of applications including packaging and labelling, textiles stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes [2]. There are polypropylene homo-polymer (PP), propylene-ethylene copolymer (PP-C), and propylene-ethylene random copolymer (PP-R) as a main different types of polypropylene which are ordinarily used in plastic containers designed for microwave heating of food.

2.2.2 History of Polypropylene

The history of polypropylene start in 1954 when a German chemist named Karl Rehn and an Italian chemist Giulio Natta first polymerized it to crystalline isotactic polymer. [3] Nowadays, the global market for this material is about 45.1 million tons, which it used in daily product such as; toys, carpeting, laboratory equipment and reusable product especially in containers.

2.2.3 Properties of Polypropylene

The properties of polypropylene make it attractive for a wide range of application, for example, it has high strength, lightness, flexibility, stability, and easy to process. Moreover, it also well suited to recycling while today's it important for environmentally conscious world. [4] Other than that, the properties of this material also can be used to replace glass, metals, cartons and other polymers. The properties include good transparency, heat resistance, low density, high stiffness, chemical inertness, steam barrier properties (food protection) and recyclability. So, a few properties of polypropylene proved that it's suitable to apply in making of food container. The mechanical properties of polypropylene also include such as inexpensive, lightweight engineering plastic is its tensile strength and stiffness. Polypropylene also has high chemical resistance, high shrinkage, high warpage, high tensile strength and tensile modulus, low elongation, high creep resistance, is able to withstand maximum exposure temperature, and has a high density.

2.2.4 Chemical Structure

Figure 2.1 shows the chain structure of polypropylene. This structure is relative orientation of CH3 on the figure with its neighborhood on the monomers gave a strong effect on the finish polymer ability to form crystals [1].

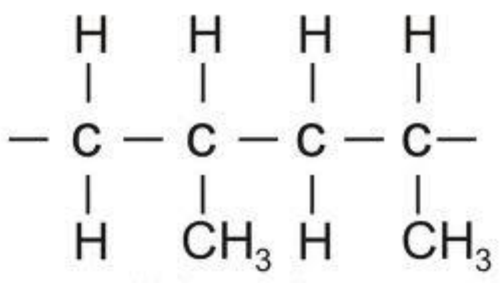


Figure 2.1: Polypropylene chain structure

2.2.5 The Uses of Polypropylene

The polypropylene used in many sectors, among industries nowadays. Polypropylene is processed into film, rigid packaging, consumer products, technical parts and also textiles. The Figure 2.2 shows the percentage of polypropylene used in a few sectors [5].

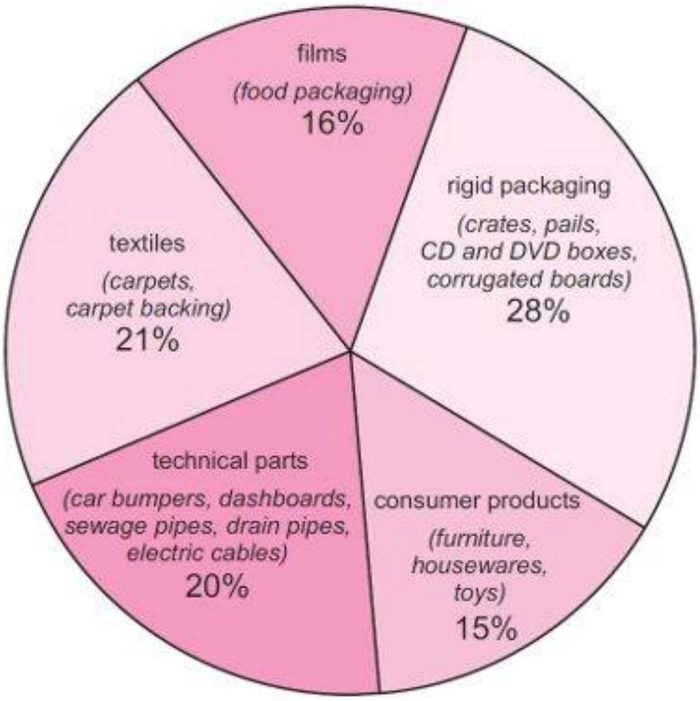


Figure 2.2: The uses of polypropylene.

2.3 THERMOFORMING

The thermoforming process is a plastic process which involved plastic sheet and forming it over a male or female mould. The typical thermoforming process involved with clamping, heating, shaping, cooling and trimming. Thermoforming is a method of manufacturing plastic parts by preheating a flat sheet of plastic to its forming temperature, then bringing it into contact with a mould whose shape it takes [6]. Thermoforming is a relatively simple processing technology. According to McKelvey [7], plastics processing is an operation carried out on polymeric materials or systems to increase their utility. Thermoforming is currently one of the most suitable production technologies for processors in operating industries, as it enables them to release new products in reduced time and with low investments in moulds and equipment [7].

Thermoforming, being the art and engineering of fabricating functional plastic parts from sheet, is maturing into a viable, competitive technology in packaging and structural parts [8].

This process commonly used in making advertising signs, cookie, candy trays and also the packaging. Figure 2.3 shows the thermoforming process for a thermoplastic sheet.

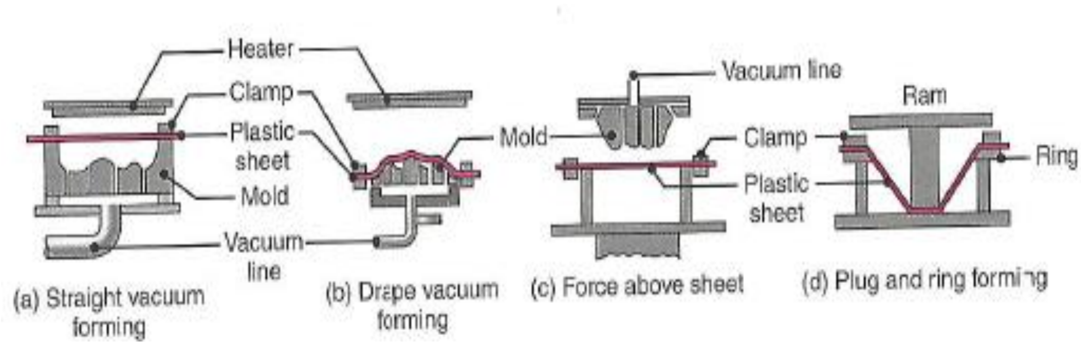


Figure 2.3: Various thermoforming process [8]

2.3.1 Type of thermoforming process

Thermoforming process has three main types which depend on upon pressure, such as vacuum forming, pressure forming and match die forming.

(a) Vacuum forming

During the vacuum forming process, the vacuum pressure is applied to form the thermoplastic sheet into the desired shape by applying heat. Then, the thermoplastic sheet is put on the mould surface. Clamping unit is used to fix the thermoplastic sheet on the mould surface. After that, vacuum is applied quickly after the sheet heated to soften. A surge tank is put-upon to pull the air out between the sheet and mould cavity. Last but not least, the shaped part is cooled before it ejected from the mould cavity. The Figure 2.4 shown the vacuum forming process [9].

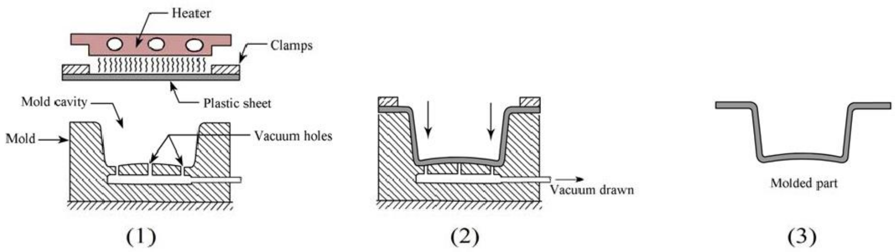


Figure 2.4: The vacuum forming processes

(b) Pressure forming

Pressure forming nearly relates to vacuum forming, but the air pressure needed much higher than the vacuum forming. Next, the preheated plastic sheet is placed on the mould surface and then air pressure is applied above the sheet as shown in Figure2.5. In between the soften sheet and the pressure box, the high pressure is developed. In a few second, high pressure can cause the preheated plastic sheet to deform into the mould cavity. The formed sheet is held in the mould cavity for cooling about few seconds. Lastly, after the part moulded solidifies the part ejected from the mould cavity [9].

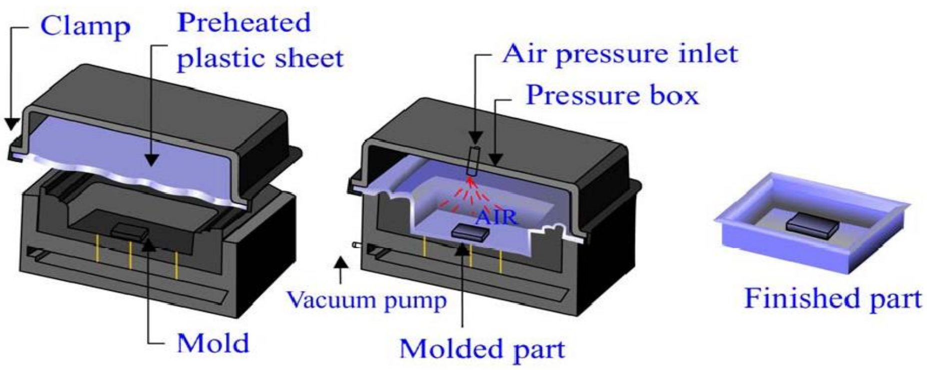


Figure 2.5: The pressure forming process

(c) Match die forming

This process also named as mechanical forming. The mould consists of two parts which is punch and dies as shown in Figure 2.6. In order to soften the thermoplastic sheet, application of heat is applied to heat the thermoplastic material.

Then preheat sheet is placed into the mould surface (also called die) and through punch pressure is applied on the hot sheet. The vacuum pump is used to evacuate the air in between the die and softened sheet and the plastic sheet follow the mould shape. Last process, the mould is ejected after the formed part is cooled.

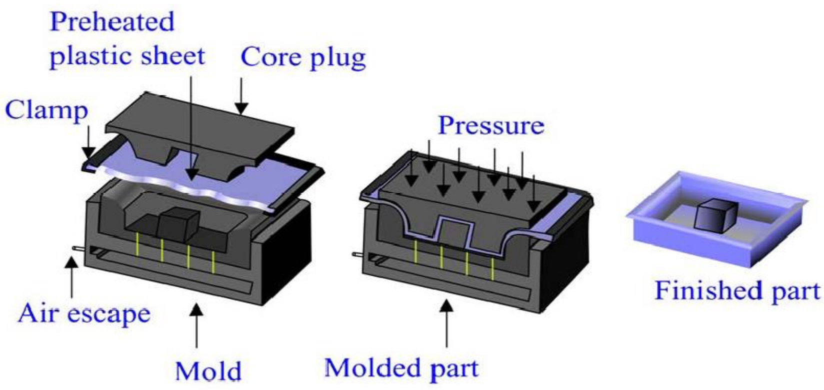


Figure 2.6: The matched die forming process

The most important parameters need to consider during thermoforming process are; mechanical pressure, heating temperature, vacuum pressure, air pressure, heating time, cooling time and also ejection mechanism. The thickness distribution strongly depends on the distribution of the sheet temperature [6].

2.3.2 THERMOFORMING POLYPROPYLENE

Polypropylene for thermoforming usually has a melt flow rate at 230^{o}c. Polypropylene types also include homopolymer which widely used to improve clarity and hardness and for melt-phase processing. Moreover, block copolymer are employed for improved impact strength at low temperature, while random copolymer are selected for high transparency and improved heat sealing quantities.

Otherwise, the polypropylene sheet for thermoforming should be produced with a highly uniform degree of crystallinity across the web. Heating also must be very uniform, both across and through the sheet thickness. Preheating is carried out at 120˚c and the final forming temperatures depend on whether solid phase or melt phase processing is being undertaken. Plus, 155˚ to 165˚ is the comment range for solid phase forming to unfilled grades of polypropylene, with 160˚ as the optimum. Table 2.1 is about the requirement for the forming properties depending on the grade [9].

Table 2.1: The solid phase forming condition picked types of polypropylene

Polypropylene type	Forming temperature range (°c)	Optimum forming temperature (°c)	Minimum is forming strain (%yield)	Maximum forming strain (%break)	Forming cycle time for 0.05in thickness (Sec)
Homopolymer	160-170	160	24	3360	28
Homopolymer, 105 calcium carbonate	155-165	160	23	3280	22
Homopolymer, 30% calcium carbonate	150-165	160	21	3190	14
Copolymer	155-165	160	22	3360	26
Copolymer, 10% calcium carbonate	150-165	160	23	3180	22
Copolymer, 30%calcium carbonate	130-155	150	80	1500	30

Recent experimental studies confirm that, even with Homopolymer, polypropylene, well-controlled thermoforming conditions allow to form deep cups with good properties such as; processing cycle time, thickness distribution, transparency, and mechanical properties. The optimizations must become more efficient because it is easier to quickly test different tool designs, process parameters and polypropylene grades.

Another experimental study is about the time-dependent temperature distribution of the total seats in the storing stage was studied for investigating the real status because the temperature distribution of the total seats after the storming stage is the initial temperature of the heating process [6].

2.4 MOULD DESIGN

There are some basic thing needs to consider in manufacturing moulds. First, the flat surfaces should be avoided because dish result may cause the sheet to stretch over the entire surface. While, the curved surface prevents the slight bumps that usually may appear in flat section. The maximum diameter required for vent hole can verify based on sheet thickness and materials used.

The used of undercut in the mould required them to provide a means to easily remove the formed product. Then, to disassemble and permitting the removal of the product, split section moulds can be designed. Careful design and manufacturing planning are necessary to assure proper channels for cooling water are core in the mould. In the design of mould, consider using the largest cavity draft angle because the larger make it better for the formed product removal. The guide for draft angle is at 2˚ to 3˚ per side for female mould and 5˚ to 7˚ for male mould [9].

2.4.1 Type of Thermoforming Moulds

There are few types of mould used in thermoforming process such as wood patterns, cast aluminium mould and machine aluminium moulds.

Wood patterns are the first type of the mould used in thermoforming process. Wood choose because it’s inexpensive and the design easily to make change. Usually, wood pattern are used to gauge general functionality of both the part and the thickness of the material [10].

Cast aluminium moulds are cast at a foundry and typically have temperature control lines running through them. This type of mould helps to regulate the heat of the plastic as speed up the production process. However, this type of mould is cost.

Machined aluminium moulds are like cast aluminium but it cut out the block of aluminium using CNC machine and some programing. Typically machined aluminium is used for shallow draw parts out of thin-gauge material. Applications may include packaging as well as trays [10].

2.5 THE COMPARISON BETWEEN THERMOFORMING PROCESS AND INJECTION MOLDING

Thermoforming process is a plastic production process that two dimensional rigid thermoplastic sheet and uses vacuum to form a sheet into three dimensional shapes like container. Furthermore, thermoforming is a single side process which it is only one side of the sheet can be controlled by the tool surface.

At another point, plastic injection moulding also can be used to produce similar application, but the difference is the cost of tooling more high than thermoforming process.

Thermoforming process has low production cost compared with injection moulding and blow moulding process. The reason is it lower forming and mould capital investment, less development time and cost and redecorating of sheet before forming. Table 2.2 shows the factors consider when comparing thermoforming and injection moulding process.

Table 2.2: The factor consider between thermoforming and injection moulding process.

	Thermoforming	Injection moulding
Material cost	Higher (sheet costs more than resin)	lower
Quantity	More (considerable waste, up to 40%)	Less (little waste)
Machinery cost	Lower than injection moulding	Higher than thermoforming
Trimming equipment	Relatively high	negligible
Production flexibility	Very high	low
Setup time	Very short	Up to 4 times as long as in thermoforming

2.6 SUMMARY

Thermoforming process growth in industry today at least 8% per year in united states, about 45% in Europe, and about 100% in pacific.

There are two aspects that make this process growth attributed. First, the development of newer process technologies that allows thermoforming to compete with other process like injection moulding and also blow moulding. Second, a general customizing trend in design of industrial products that requires less total part per design that range from small to very large products.

Three dimensional thermoforming solid form plastic provide great variety in size, shape and quantities of marketable products, from millions of ounces-size drinking cup or container to thousands of pickup truck storage wells and so on.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discuss on method and parameter used for preparation and fabrication of thermoplastic container. In this methodology process, there were few stages that have been involved to complete this thermoplastic container. This process started with designing the mould for the container using Catia V5 software, followed by fabricated the moulds from aluminium block using CNC milling machine, drill the vent holes for the vacuum forming applied, and form the container using polypropylene sheet material. The flowchart of this experiment that was carries out in this study is shown in Figure 3.1

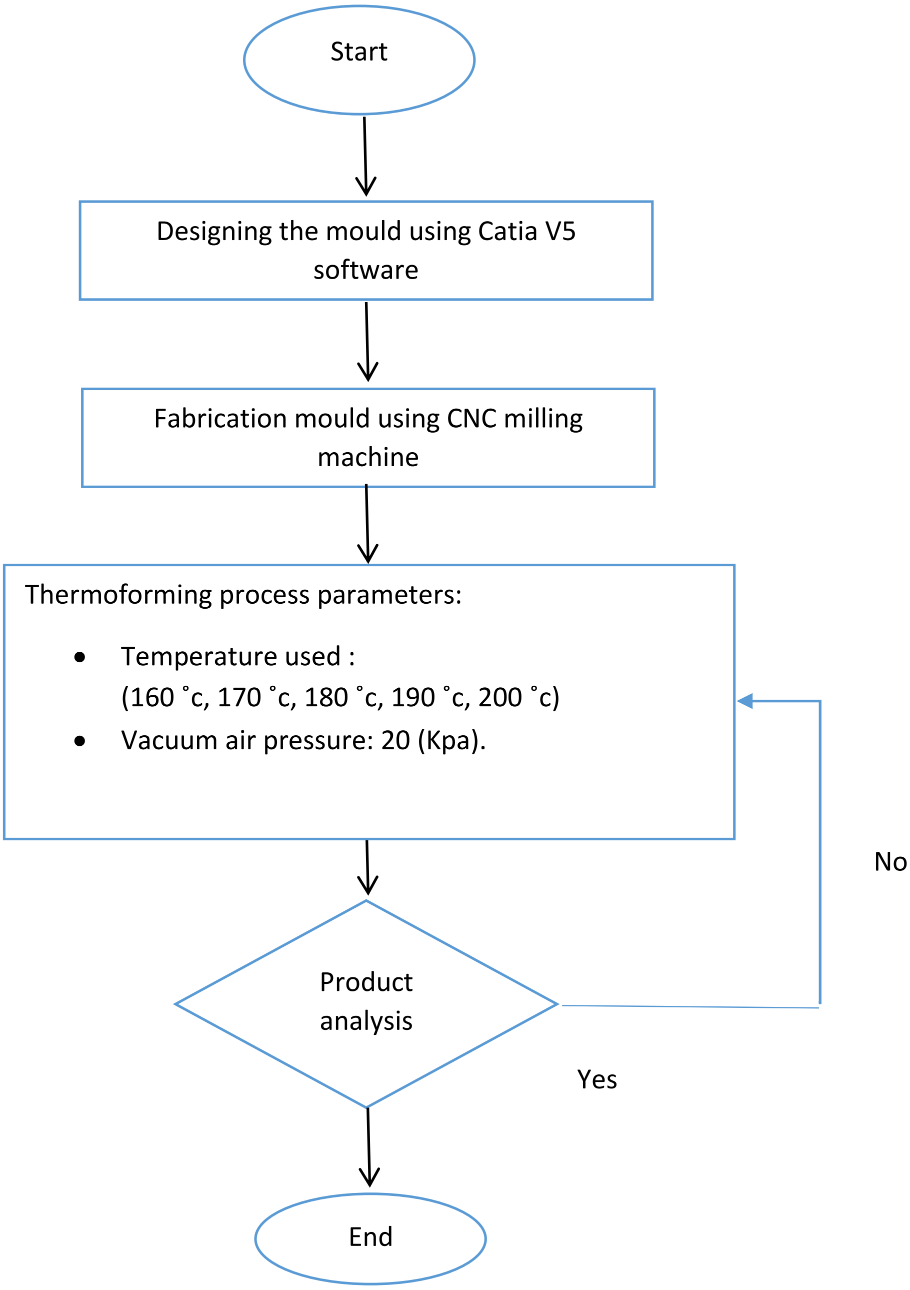


Figure 3.1: Methodology flow chart

3.2 RAW MATERIAL

There were two types of material used in this process of preparation thermoplastic container. First, the material used for fabricating the container mould was aluminium. Second, the thermoplastic material used for fabricating container was polypropylene sheet.

For the fabrication of mould, aluminium was choosing because it has temperature control lines running through them and able to regulate the heat of the thermoplastic being formed. Based on previous study, wood, plastic and also epoxy were used as a mould but these all materials not temperature controlled mould. In the recent study, aluminium and other metal type material was chosen for thermoforming moulds because of its properties. There were few benefits of using aluminium as a thermoforming mould, such as, machine ability and high thermal conductivity. In a few research, high production thermoforming mould used were made of aluminium because aluminium moulds contain channels through which water, the primary cooling medium was pumped. The cooling rate and the temperature controlled. The temperature and cooling rate were also the reason of shrinkage and other attributes of thermoforming part. The aluminium block was shown in figure 3.2.

Figure 3.2: The aluminium block

The polypropylene as the thermoplastic material used for the container in thermoforming process. The advantages of polypropylene grades include quality of sheet, the wall thickness and uniformity part, dimensional stability and also regrind used. The thickness of plastic sheet should be less than the diameter of vent holes. The PP sheet used in this process type was, size 300mm x 210mm x 1mm thickness and milky-white color. This was showns in Figure 3.3. The data sheet for the properties of this PP use was shows in figure 3.4.

Figure 3.3: The Propylene sheet

TYPICAL RESIN PROPERTIES [(a)]	UNIT	TITANPRO SM198	ASTM METHOD [(b)]
Melt Flow Rate, at 230°C	g/10 min	**1.6**	D1238
Density	g/cm^3	**0.9**	D1505
Tensile Strength at Yield	kg/cm^2	**290**	D638
Elongation at Yield	%	**14**	D638
Flexural Modulus	kg/cm^2	**11000**	D790B
Notched Izod Impact Strength at 23°C	kg·cm/cm	**34**	D256A
Heat Deflection Temperature at 4.6 kg/cm^2	°C	**78**	D648
Rockwell Hardness	R scale	**77**	D785A
Water absorption after 24 hours	%	**0.02**	D570

(a) Values shown are average and are not to be considered as specifications.
(b) ASTM test methods are latest under the Society's current procedures.

Figure 3.4: The PP sheet properties [11]

3.3 DESIGN THE MOULD

According to the flow chart in Figure 3.1, the preparation of thermoplastic container starts with the design. The container was designed by using Catia V5 software. The standard size for mould was less than 130mm width and 200mm length according to the size of the thermoforming plate mould. Draw ratio = depth of part/width of part. Draw ratio should be less than 2:1 for female moulds or 7:1 for male mould.

The mould design guidelines for parts need to consider through draft angle. The draft angle for male mould minimum was three degree, and for female mould draft angle minimum was one degree. The draft need to consider because of the thermal expansion of the plastic during thermoforming process. The coefficient of thermal expansion caused it shrink to the plastic part. The function of draft also to allows for better material distribution by opening up a corner area to allow clearance for a plug assist to push material or part. The drafted walls have less risk of plug hitting the sidewall. The larger the draft angle, the better in keep the end use requirements of product.

3.4 PREPARATION OF THE MOULD

3.4.1 The Raw Material

The raw material, aluminium block cut by using band saw for container and for container's lid. Figure 3.5 show the band saw using to cut the aluminium block. The aluminium block squaring manually by using milling machine before generate G-code. Figure 3.6 below shows the milling machine squared the aluminium block. The size for container size of squaring was 100mm x100mm x50mm and for their cover is 100mm x 100mm x 30mm.

Figure 3.5: The band saw cutting the aluminium block

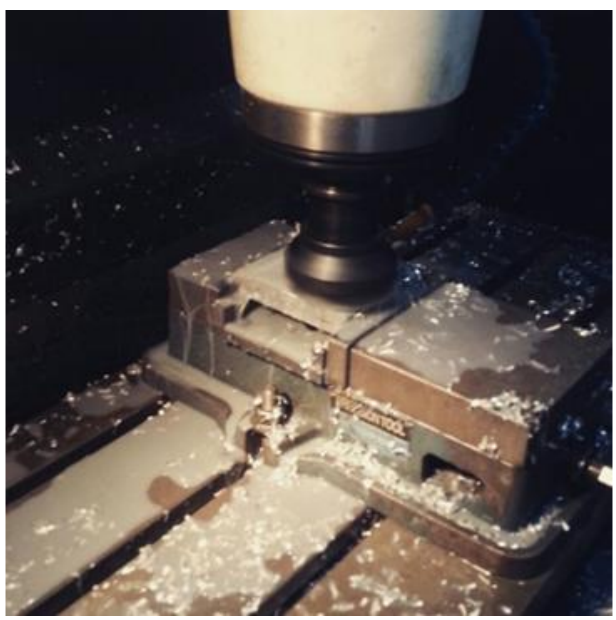


Figure 3.6: Squaring an aluminium block

3.4.2: Machine the Mould

After the design of container shape, the drawing was then put into action where the profile drawing machine on the aluminium block of the mould. The machining process carried out to machine the container shape. The CNC milling machine and some sort of CAD program used to cut out a solid block of aluminium. The Figure 3.7 show the CNC milling machine the container's mould.

There are some type of tools used to machine this container's mould such as End mill 10 mm for pocketing, end mill 12mm for roughing and ball nose 12mm for sweeping process. Table 3.1 shows the list tools used in machining the container's mould.

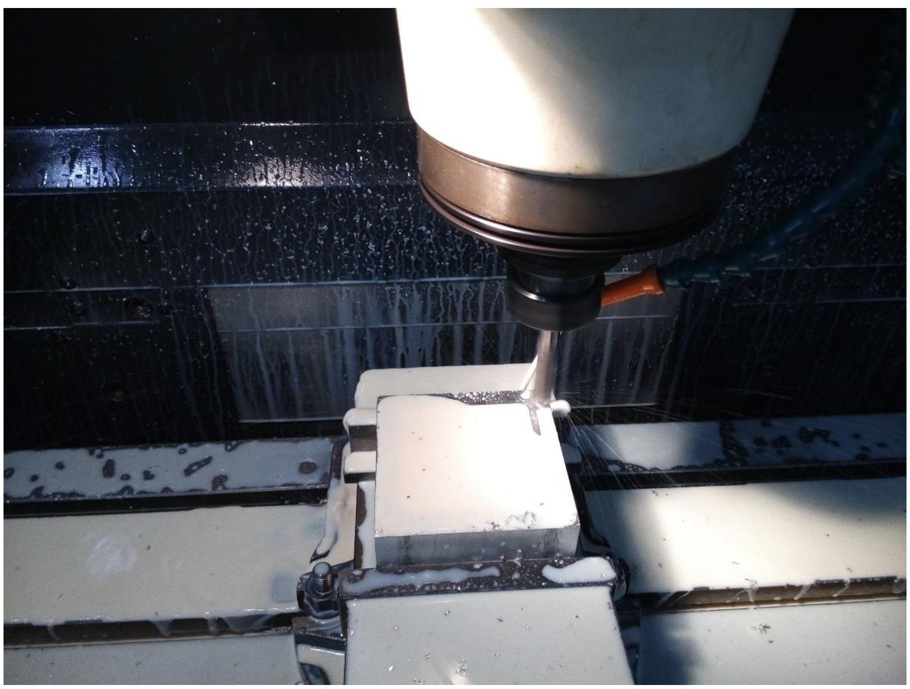


Figure 3.7: The aluminium block machine the container's mould

The lid of the container machined shows in Figure 3.8 below. The mould draft angle, texture, depth need to consider in order avoiding scuffing during the extracted part from the mould. The table 3.1 show the tool used to machine this lid is 2mm end mill for the slot 3mm.

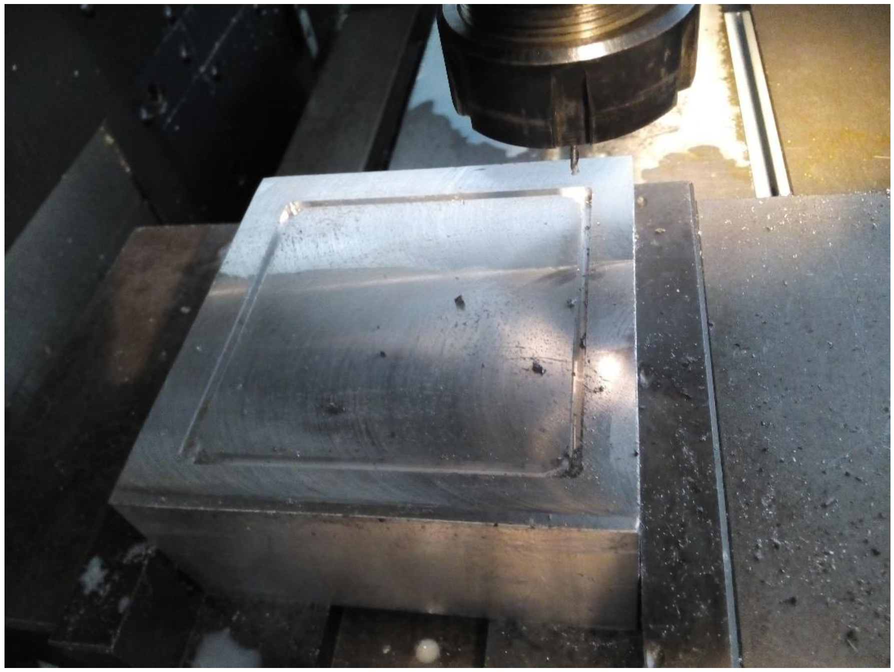
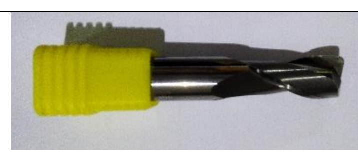
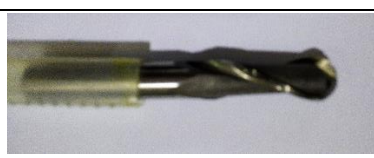


Figure 3.8: The lid mould of the container

Table 3.1: The list of tools used in fabricate container mould.

Tool	Size		
End mill	 10mm	 12mm	 2mm
Ball nose	 12mm		

3.4.3: Drill the Vent Holes

The most important is the vent hole drilled to the mould, the diameter less than the thickness of the PP sheet. Vent holes are drilled and placed in all the lower parts of the mould to provide for easy escape of trapped air.

Type of mould used for this container is female mould. Female mould parts are formed in the mould and must be taken out upon removal. The Figure 3.9 shows the holes drilled to the mould. The diameter of drill tools used 1mm.

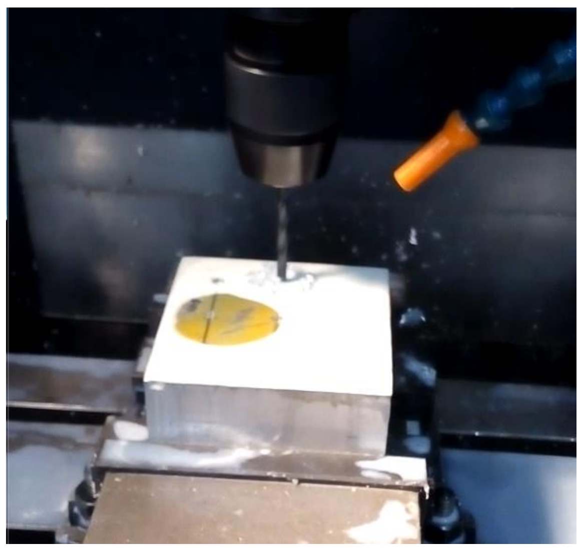


Figure 3.9: The drilling process of vent holes

3.5 THERMOFORMING PROCESS

The thermoforming process type used in this project is a vacuum forming process as shown in Figure 3.10. A vacuum is formed between the mould cavity and the thermoplastic sheet. The basic processes for this thermoforming operation are, first the flat thermoplastic sheet is clamped. Second the sheet heated to its softening temperature (the temperature depends on the type of material used). Next, the force against the shape of mould form of vacuum pressure. The pressure used in this process is constant at 20 kPa.

Figure 3.10: Thermoforming machine used

There are few stages involved in the vacuum forming process. Firstly, the mould was made from an aluminium material machine with the shape of container. Secondly, the mould shape placed in vacuum former. Thirdly, a sheet of polypropylene is clamped in the frame. Next, the polypropylene sheet heated and sealed to the container mould. Then, the vacuum is turned on and pumps out all the air. At this stage the shape of mould can be clearly seen through the plastic sheet. The plastic has cooled sufficiently the vacuum pumps switch off. After that, the plastic sheet removed from the vacuum part and the sheet has the shape as mould shape. Lastly, the excess plastic is trimmed so that the plastic container remains.

3.5.1 Parameter Setting

During the thermoforming process, the temperature need to control. The parameter setting is the guideline setting for thermoforming process that must be following to prevent shrinkage. The temperature of the thermoforming depends on the material used. For the polypropylene material, the recommendation temperature for PP formed is 165˚ C to 180˚ C. Sometimes, the temperature depend on the thickness of the plastic sheet itself, the machine used and also the type of mould. In this project, the experimental parameter of temperature set start form 160°C until 200°C. This experimental was conduct to identify the best parameter temperature used during process of thermoforming. The temperature controlled start from 160˚C, 165˚ C, 170˚ C, 175˚ C, 180˚ C, 185˚ C, 190˚ C, 195˚ C, and 200˚ C. The temperature sensor used to as the equipment to control temperature as shows in Figure 3.11. The vacuum pressure use is constant at 20psi. The vacuum pressure forces the sheet to forming to the mould and form the desired shape of the part. Then, the thermoformed part shape cooled.

Figure 3.11: the temperature sensor used to measure temperature

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this study, the thermoplastic container produced by thermoforming process. This chapter shows the result preparation of thermoplastic container via thermoforming process. The result shows the temperature increase effect the thickness of the container produces. The factor that the process was unsuccessful to form was also discuss in this chapter. The good design for container may prove by drop test as a result.

4.2 EXPERIMENTAL RESULT

4.2.1 The Design

The squared shape of the container was designed successfully in this project. The container successfully design by using Catia V5 software, in detail dimension for mould are in Figure4.1 below, the type of mould designed was female mould in square shape. Figure 4.1 and Figure 4.2 show the container design by Catia V5 software. The type of mould for container is cavity mould or female mould.

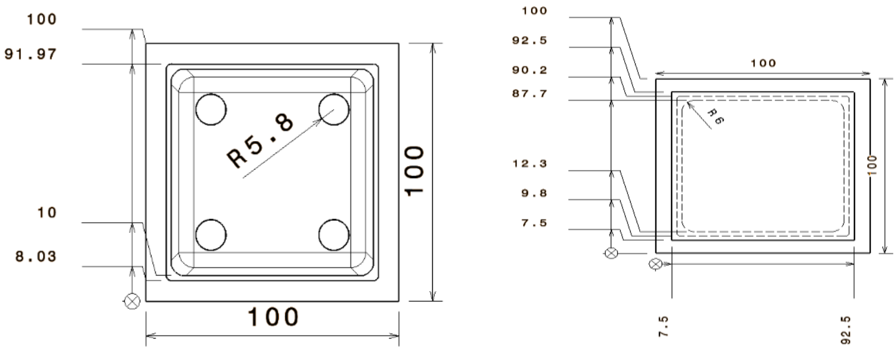


Figure 4.1: The details dimension

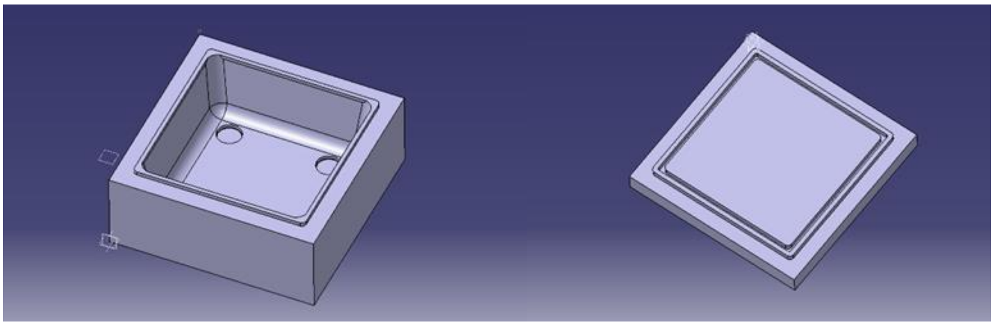


Figure 4.2: The mould designed by Catia V5 software

4.2.2 The Mould

The aluminium block machined using CNC milling machine and some short of g-cod program to follow the design of mould in Catia software. The Figure 4.3 showed the machine aluminium mould and its lid mould.

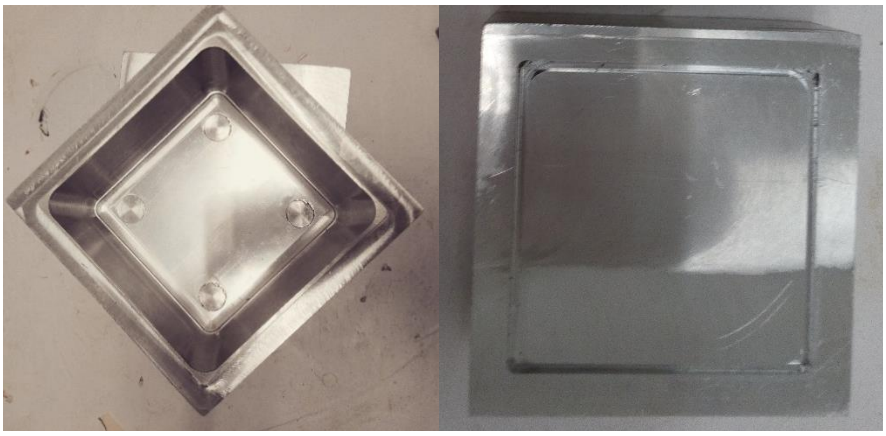


Figure 4.3: The aluminium mould

4.2.3 Result for Container Part

This thermoforming process start with clamp a thermoplastic sheet in a frame. The machine thermoforming need to be warm up by heat the hater part about 100^{0}c and above before start heat the plastic sheet. The plastic sheet clamp in a frame as shown in Figure 4.4. Then, the PP sheet heated until it achieved sag point.as shows in figure 4.5.

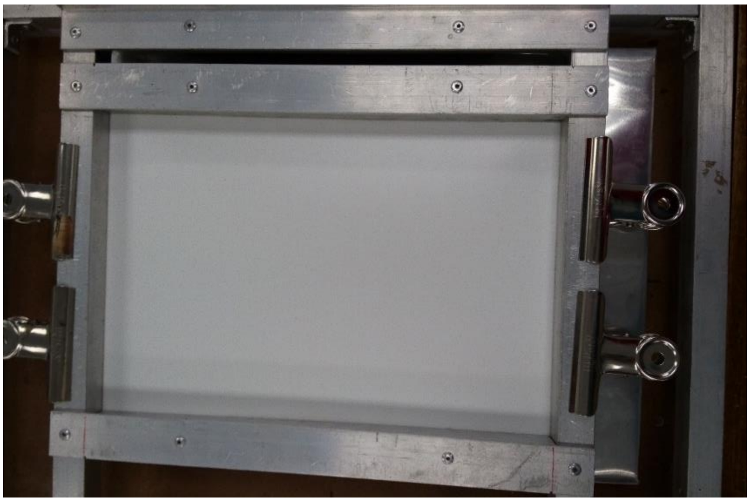


Figure 4.4: The PP sheet is clamped in a frame

Temperature was ones of the important things to control during this process such as PP sheet temperature during heating time. The heat time for PP with 1 millimetre (mm) thickness was recommend 50 seconds in theory but sometimes it depend on the machine thermoforming itself. In this experiment the time to reach sag point is 2minutes 20 seconds is the best.

Figure 4.5: The plastic sheet at sag point

Next, applied the constant vacuum pressure at 20 kPa to the plastic to the mould so that the vacuum can be applied. Then the shape of the container form as shows in Figure 4.6 below.

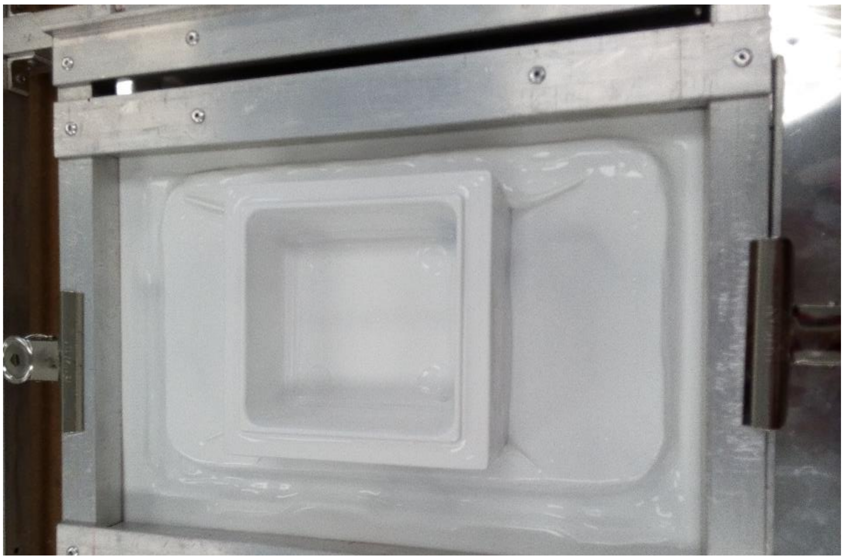


Figure 4.6: The PP sheet formed by applied vacuum

After that the part of the container need to eject and the excess plastic is trimmed off. Figure 4.7 is the shows excess plastic need to trim off after ejection form the mould. Lastly, the thermoplastic container part successful form by thermoforming process as shows in Figure 4.8. This can be conclude that the female mould for the container successful design and thermoform.

Figure 4.7: The excess plastic

Figure 4.8: The container’s thermoplastic part

4.2.4 Result for Lid Part

The lid part design as female mould at first cannot be completely thermoformed because of the limitation of drill tools diameter less than 1milimeters (mm) for vent holes. This mould need to drill diameter less than 1mm because the slot dimension was 2mm, this may risk the part to drill at the corner side. The male mould designed to solve this problem and to also can compare which type of mould suitable using vacuum forming process. Figure 4.9 shows the male mould design for lid. As previous chapter the minimum draft angle for male mould was 5^0. Figure 4.10 shows the result of lid after thermoforming process. As the result, container’s lid forming bubbles within the plastic's inner layers.

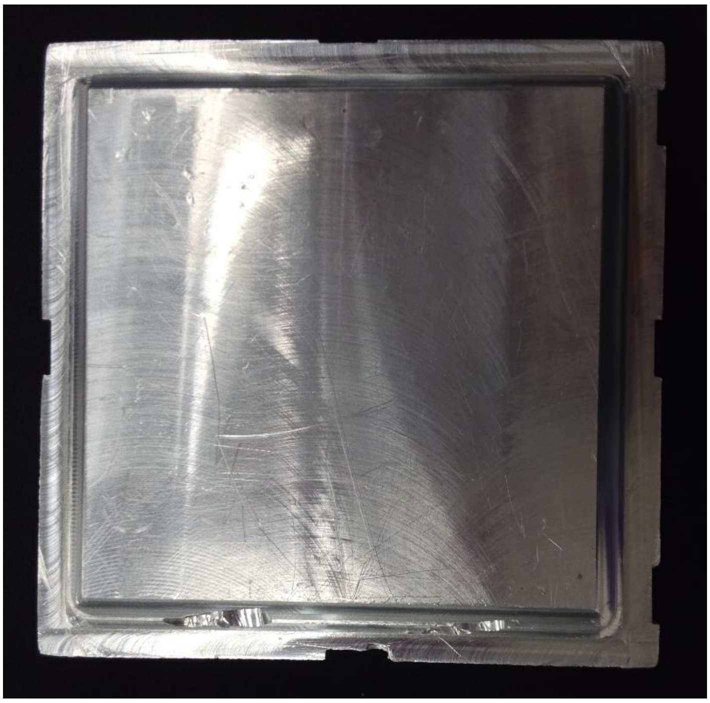


Figure 4.9: The male mould used

Figure 4.10: The lid part

4.2.5 The Result for Temperature Parameter Used

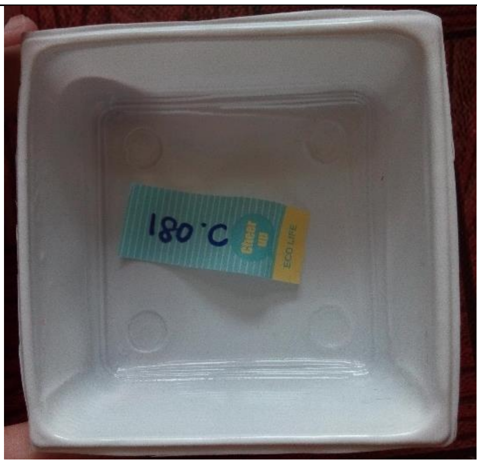
The temperature used to heat PP sheet at 160^0c to 200^0c to identify which temperature is the best in this experiment. The recommendation temperature used for PP sheet is 165 ^{0}c to 180^0c but this also depend on the type of machine and the thickness of PP sheet. In this range temperature, the result shown the temperature in range 165^0c to 175^0c is good temperature compare to other temperature during the thermoforming process but 175^0c is the perfect surface. Table 4.1 below shows the result of container with different temperature used.

The data was record during thermoforming process shows in Table 4.2. based on the table below it shows that the increasing the value of temperature, the time taken become longer and the plastic part closed to melting molten plastic which it cannot form good shape of the container.

Table 4.1: The result for each temperature

TEMPERATURE USED	RESULT	DESCRIPTION
160^0c		• At this temperature the container shape follow the mould design but the bottom thickness of the container not uniform.

156^0c		• The container form is good.
170^0c		• At this temperature of PP sheet heating form good surface of container.
175^0c		• This temperature is better than 170^0c and 165^0c

180^{0}c		• 180^{0}c cannot be recommended as temperature of forming because at this point the PP sheet started wrinkle at the side wall part.
185^{0}c		• This temperature produced bad surface of container.
190^{0}c		• The plastic container wrinkle at the top side wall of the container.

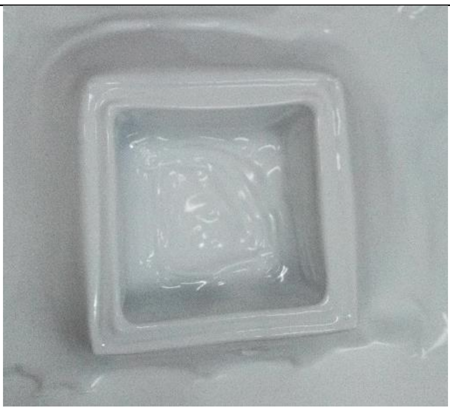
195^0c		• The wrinkle increases at high temperature.
200^0c		• Too hot temperature at 200^0C, causes the result of container fail to forming perfectly at this temperature.

Table 4.2: The data record during thermoforming process

No.	Room temperature	Temperature of mould	Temperature of PP sheet	Time taken for PP sheet	Vacuum pressure applied (kPa)
1	27^0c	40^oc	160^oc	1min 40 second	20
2	27^oc	40^oc	165^oc	2min	20
3	27^0c	40^oc	170^oc	2min 20second	20
4	27^0c	40^oc	175^oc	2min 30 second	20
5	27^0c	40^oc	180^oc	2min 50 second	20

6	27^0c	40^oc	185^oc	3min 05 second	20
7	27^0c	40^oc	190^0c	3min 30 second	20
8	27^0c	40^oc	195^0c	3min 50 second	20
9	27^0c	40^0c	200^0c	4min	20

4.3 DISCUSSION

4.3.1 Mould design

The mould design for container is successfully formed as shows before, but the design for lid is fail to form perfectly because of the bad design for male mould. The lid for male mould need to increase the draft angle of the part more than 5^o because the aluminium thickness was highs. The bubbles form because the lid's mould has flat surface. As the conclusion, from this preparation thermoplastic container the lid design must be female mould also.

4.3.2Mould effect

This grid ink was placed on the top of the plastic sheet to see the stretch mark area and the thickness of plastic part form. Figure 4.11 shows the stretch mark for temperature 170^0c outside mould wall area which has a lower thickness than the bottom area. This caused by the hot sheet contacts with the outside wall area of the mould at first step in the female mould and consequently the sheet sticks to the mould. Then, all deformation takes place on the bottom area of the container. The outside mould wall area was the excess material need to trim off so the thickness of the container was uniform since the part of bottom area and inside wall not at high stretching area.

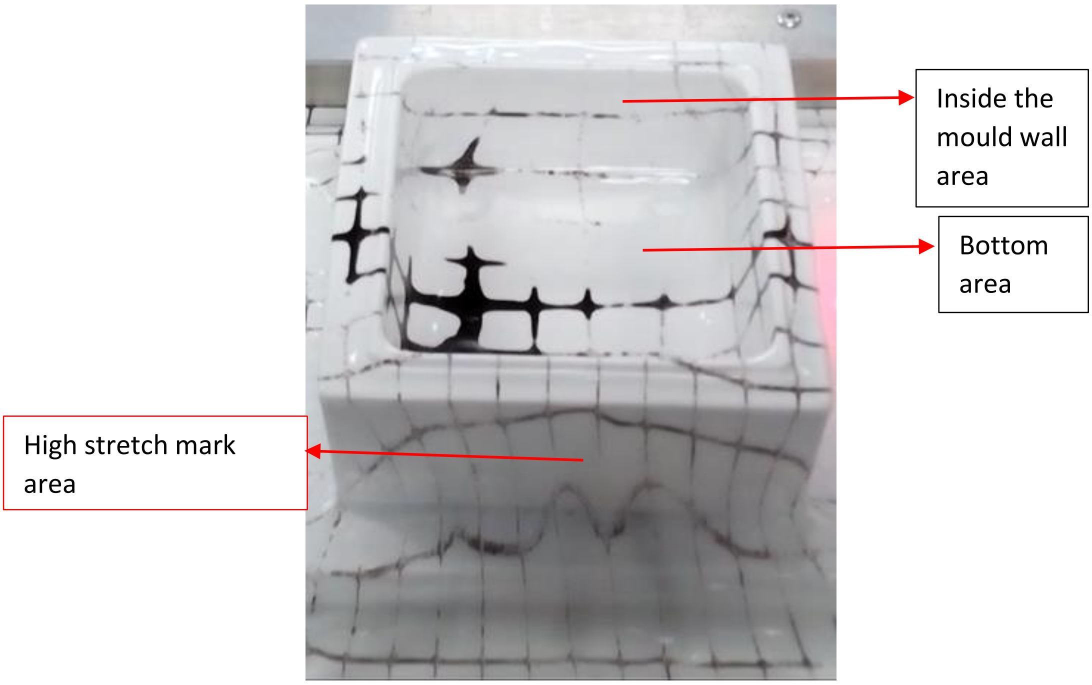


Figure 4.11: The stretch mark (170^{0}c)

The stretch mark area shows in figure 4.12 below is for 200^{0}c heating temperature. This temperature is too hot and causes the stretch area tears.

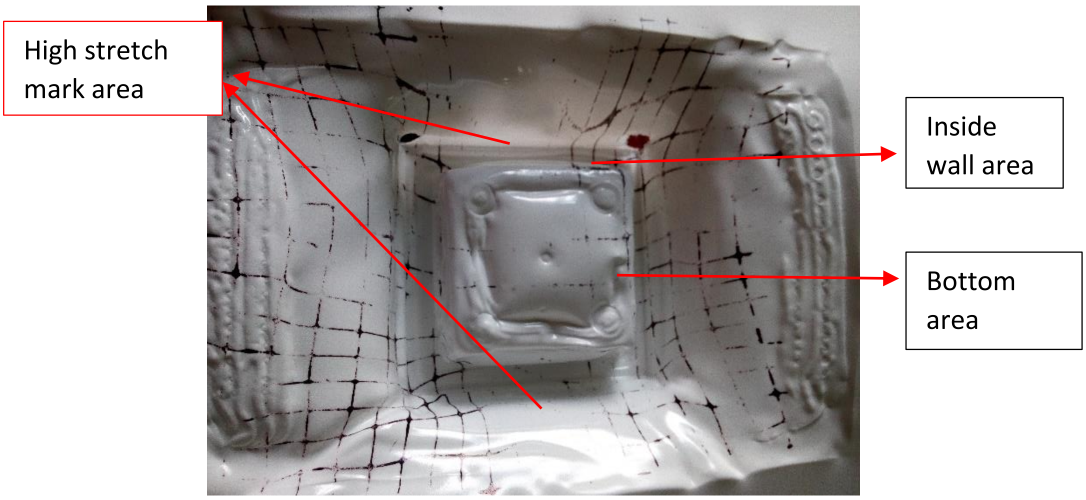


Figure 4.12: The stretch mark for (200 ^{0}c)

Based on the observation from both picture the stretch mark high at the side wall area, at this area the thickness of the plastic is lower or thin. But, this stretch area at the outside of the container. From this observation, the female mould is the best design for vacuum forming. This discussion proved based on the previous research about Numerical and Experimental Analysis of HIPS Sheets in Thermoforming Process by author Mohammad Ghobadnam Peiman Mosaddegh & Masood Rezaei Rejani & Hosein Amirabadi &Abbas Ghaei. Published 13 September 2014. [12]

4.3.3 The Vent Holes effect

The size of vent holes drill to the mould must be less than the thickness value of plastic sheet as mentioned in the theory in previous chapter 2. The diameter of vents holes drill for the container part was 1mm this effect the plastic part surface as shows in Figure 4.13 below, the holes mark at the plastic part because the size of holes 1mm equal to the thickness of PP sheet.

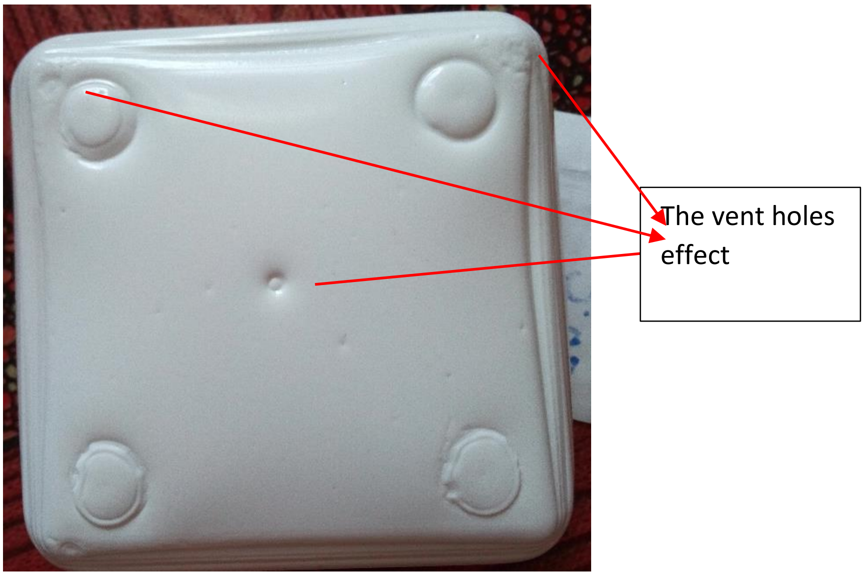


Figure 4.13: The effect of vent holes

Figure 4.14: The vacuum hole

Other than that, the numbers of vent holes platen used is one of the factors that affect the vacuum pressure applied to the plastic sheet. The vacuum hole in this machine is shown in Figure 4.14. The Figure 4.15 is the result when used the vacuum hole in Figure 4.14. This one hole was not strong enough to force the plastic sheet over the mould.

Figure 4.15: The result when use vacuum holes without platen

To make the vacuum air pressure can apply at all areas of the mould the platen full with holes was used as shows in Figure 4.16. This platen make the vacuum air pressure applied at each side wall of the container. The result of use this platen shows in Figure 4.17.

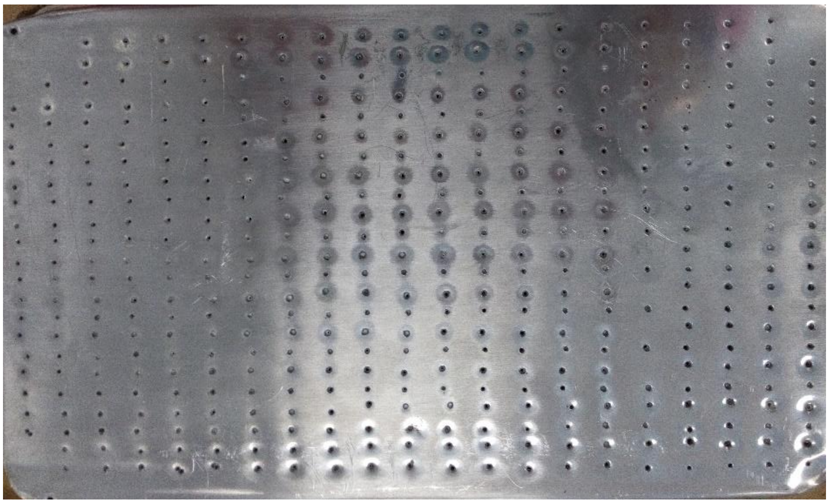


Figure 4.16: The platen used

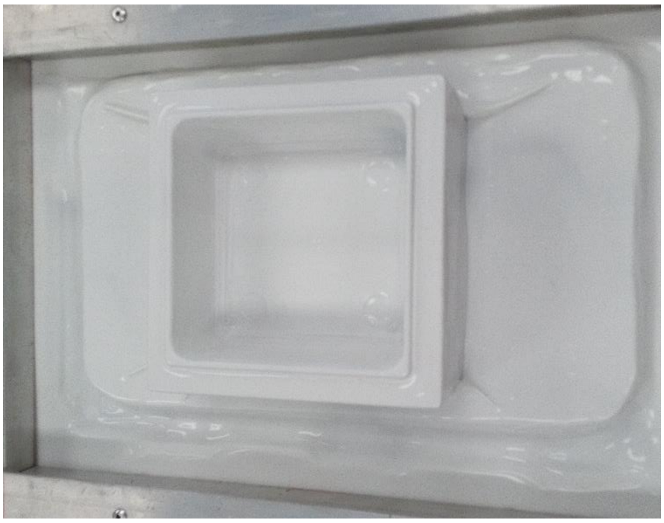


Figure 4.17: The result for platen used

4.3.4 The Melt Phase Thermoforming Troubleshooting

As shown in the result before the temperature of the heating PP sheet effect the plastic part forming. The reason of the effect during this process was shown in the Table 4.3. The main problem or troubleshooting occurred was from the parameter heating temperature. This proved that the temperature is the important parameter in thermoforming process.

Table 4.3: The thermoforming troubleshooting

Troubleshooting	**Reason**	**Solution**
Poor part detail	• Sheet temperature too low • Insufficient vacuum	• Increase the heater temperature before heat the sheet • Check the holes, increase number vacuum holes.
Ununiformed colour or surface	• Incorrect sheet temperature used	• Check the temperature correctly
Sheet tear while forming	• Temperature of the sheet too hot.	• Control the temperature in recommendation temperature.
Sheet webbing, wrinkling	• Sheet temperature too high • Webbing can also occur when a mould was too large or parts of the mould were too close together.	• Decrease heating temperature for the sheet
Dimples on mould side of part	• The vacuum holes was not less than plastic sheet thickness.	• Decrease the holes diameter

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter discuss the conclusion of the thermoforming process for thermoplastic (PP) container based on the result in the previous chapter 4. Plus, this chapter also include recommendation and suggestion for future research to make better thermoplastic container.

5.2 CONCLUSION

This research study is basically an application of thermoforming process where the main study of plastic process in industry nowadays, and to identify the main advantage of thermoforming process compare to other plastic part process in industry today. The main of this experiment also, to test the process of thermoforming process based the mould design for the container.

This experiment also to identify the suitable temperature and time range used for heating temperature Polypropylene (PP) sheet during process of thermoforming.

Based on these experiments that were done, it can be concluded that the experiment successfully fulfils the first objective that was to design and fabricate the mould. The female mould was the best design for vacuum forming process.

For second objective, to fabrication Polypropylene thermoplastic container by thermoforming process. The thermoforming process successfully formed the container based on the mould designed, but not successful for the lid part.

There are some PP sheets not form perfectly during the process because the temperature not suitable and the pressure was released on two earlier causes the plastic soul before it form. This experiment proves that the different temperature used during these thermoforming will get different result either on the surface uniformity or the thickness. Based on the result, the suitable parameter temperature used for this thermoplastic PP container is in range 165^0c to 175^0c. As for the conclusion, the factors that affect thermoforming process is the mould design, vent holes and heating temperature for thermoplastic.

5.3 RECOMMENDATION

For the future works to improve the study of this topic, the following recommendations were being suggested:

i. The thermoplastic thickness should greater than the value of the vent holes diameter.
ii. Perform preheating on the mould for the process of thermoforming rather than just heat the thermoplastic (PP) sheet.
iii. Do some simulation for thermoforming process using ANSYS software. This software suitable for analysis of thermoforming process.
iv. Perform mechanical testing on the final product such as drop test, flexural test, hardness test in order to investigate the strength and functionality of the product.

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APPENDIX A

Data sheet of PP

LOTTE CHEMICAL
TITAN

Product Data

TITANPRO SM198

FOR BLOW MOLDING, SHEET EXTRUSION AND INJECTION MOLDING

CHARACTER

Polypropylene random copolymer.
Titanpro SM198 is a clarified grade designed for high transparency articles.
The base resin meets the requirements of the U.S. Food and Drug Administration as specified in 21 CFR 177.1520(a)(3)(i) and (c)3.1a. The adjuvant meet their respective FDA regulations and 21 CFR 177.1520(b). In summary, this resin meets the FDA criteria covering safe use of polyolefin articles and component of articles intended for food contact use.
TSCA Registry: CAS# 9010-79-1.

APPLICATIONS

Injection and extrusion blow molding containers.
Extruded sheet for thermoformed containers and lids, etc.
Multilayer coextruded structures and sheet.
Injection molded articles requiring high toughness.

ADVANTAGES

Superior clarity. Low odour & taste. Hot fillable.
Good rigidity and impact resistance.
Cycle time reduction with low processing melt temperature.
Utilities cost saving and process versatility.

FABRICATION

Equipment - general injection, extrusion blow molding, sheet extrusion and thermoforming machines.
Techniques - standard processing.

TYPICAL RESIN PROPERTIES [(a)]	UNIT	TITANPRO SM198	ASTM METHOD [(b)]
Melt Flow Rate, at 230°C	g/10 min	1.6	D1238
Density	g/cm³	0.9	D1505
Tensile Strength at Yield	kg/cm²	290	D638
Elongation at Yield	%	14	D638
Flexural Modulus	kg/cm²	11000	D790B
Notched Izod Impact Strength at 23°C	kg·cm/cm	34	D256A
Heat Deflection Temperature at 4.6 kg/cm²	°C	78	D648
Rockwell Hardness	R scale	77	D785A
Water absorption after 24 hours	%	0.02	D570

(a) Values shown are average and are not to be considered as specifications.
(b) ASTM test methods are latest under the Society's current procedures.

Shrinkage : 1.3 - 1.4% depending on the product wall thickness and molding parameters.

R00

LOTTE CHEMICAL TITAN (M) SDN. BHD. (Formerly known as Titan Petchem (M) Sdn. Bhd.) (154990 W)
PLO 312, Jalan Tembaga 4, Pasir Gudang Industrial Estate, 81700 Pasir Gudang, Johor, Malaysia.
T+607. 253 8888 F+607. 251 7881 E www.lottechem.my

Titanex® • Titanlene® • Titanzex® • Titanceed® • Titanpro®

APPENDIX B

Band Saw Cutting Machine

APPENDIX C

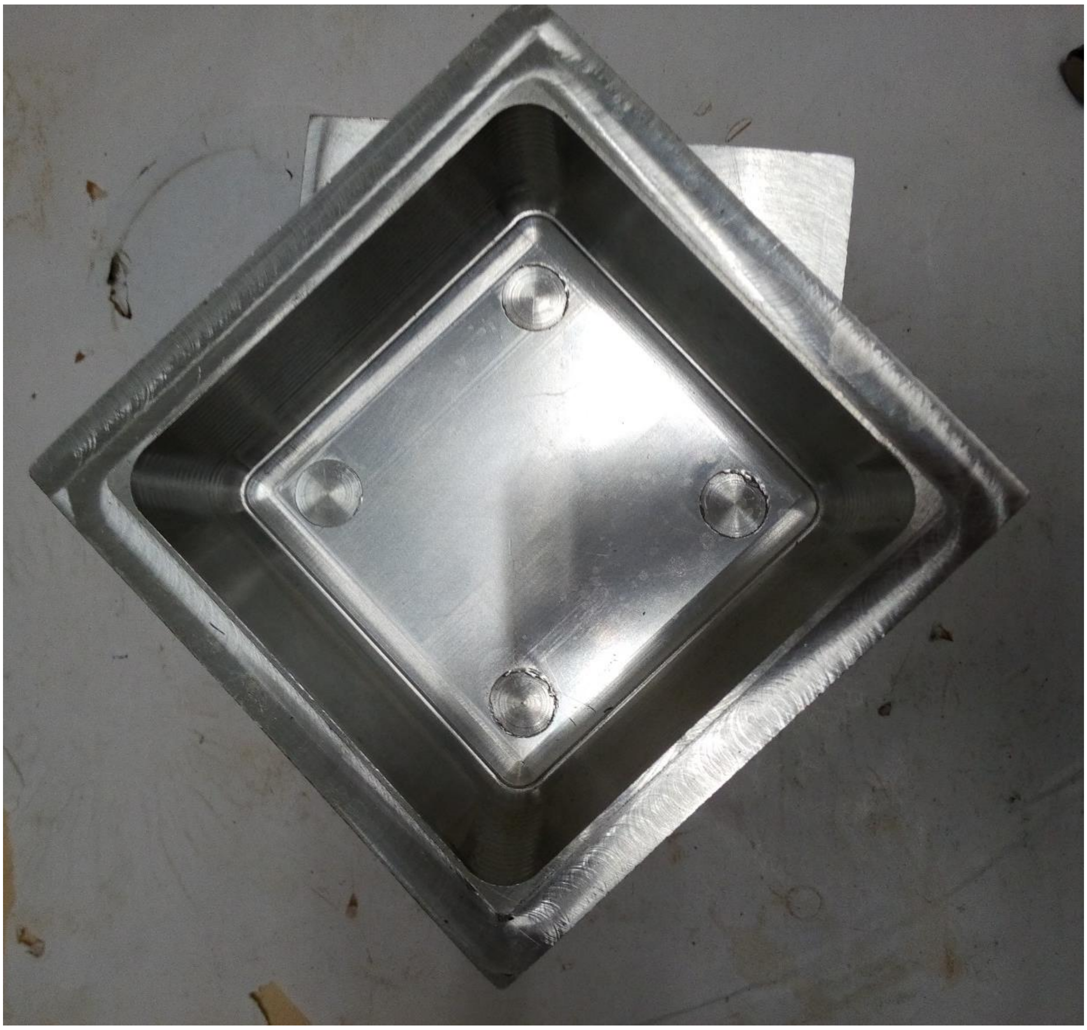
Makino Milling Machine

APPENDIX D

Thermoforming Machine

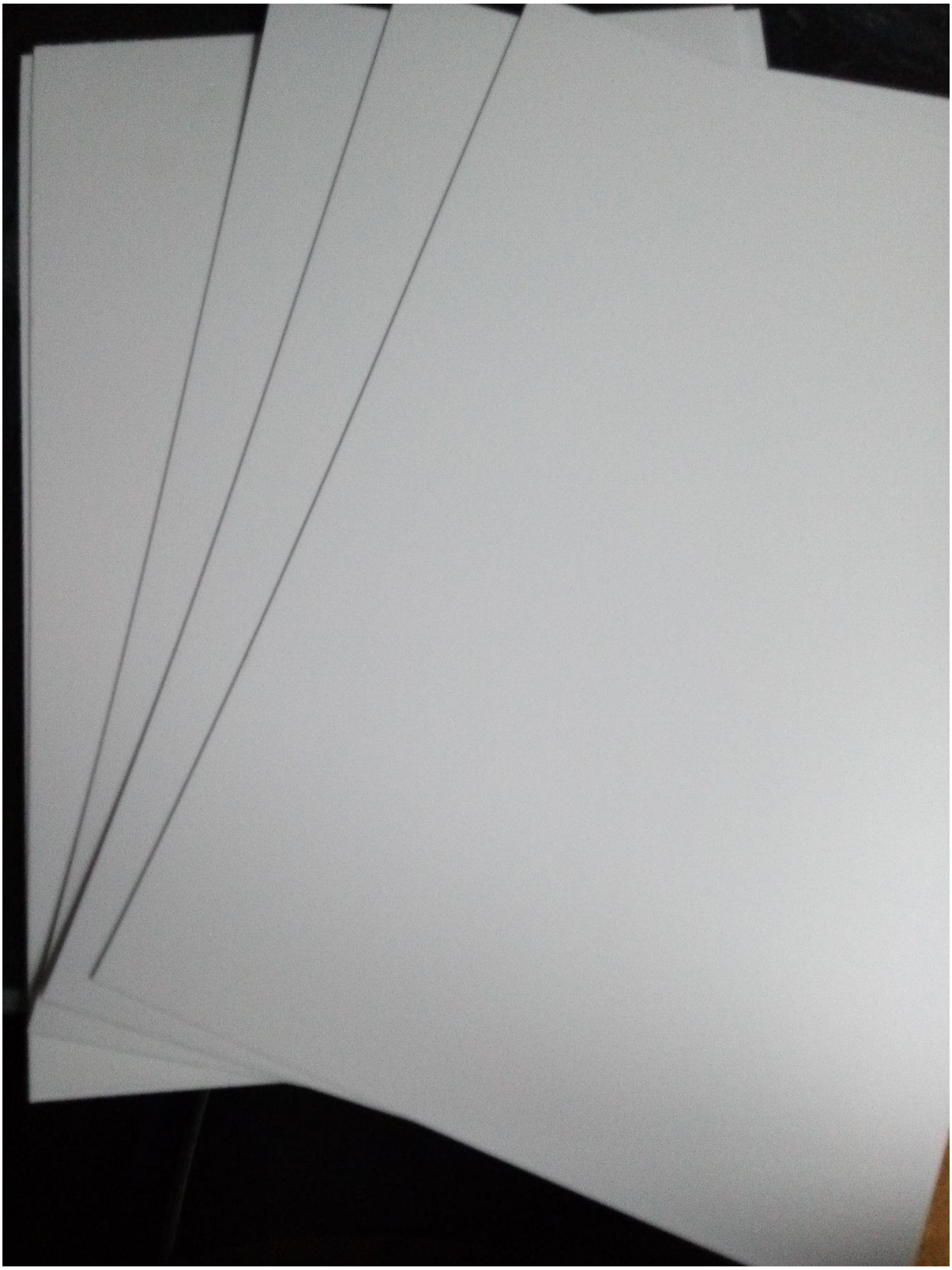
APPENDIX E

Mould



APPENDIX F

Polypropylene PP Sheet



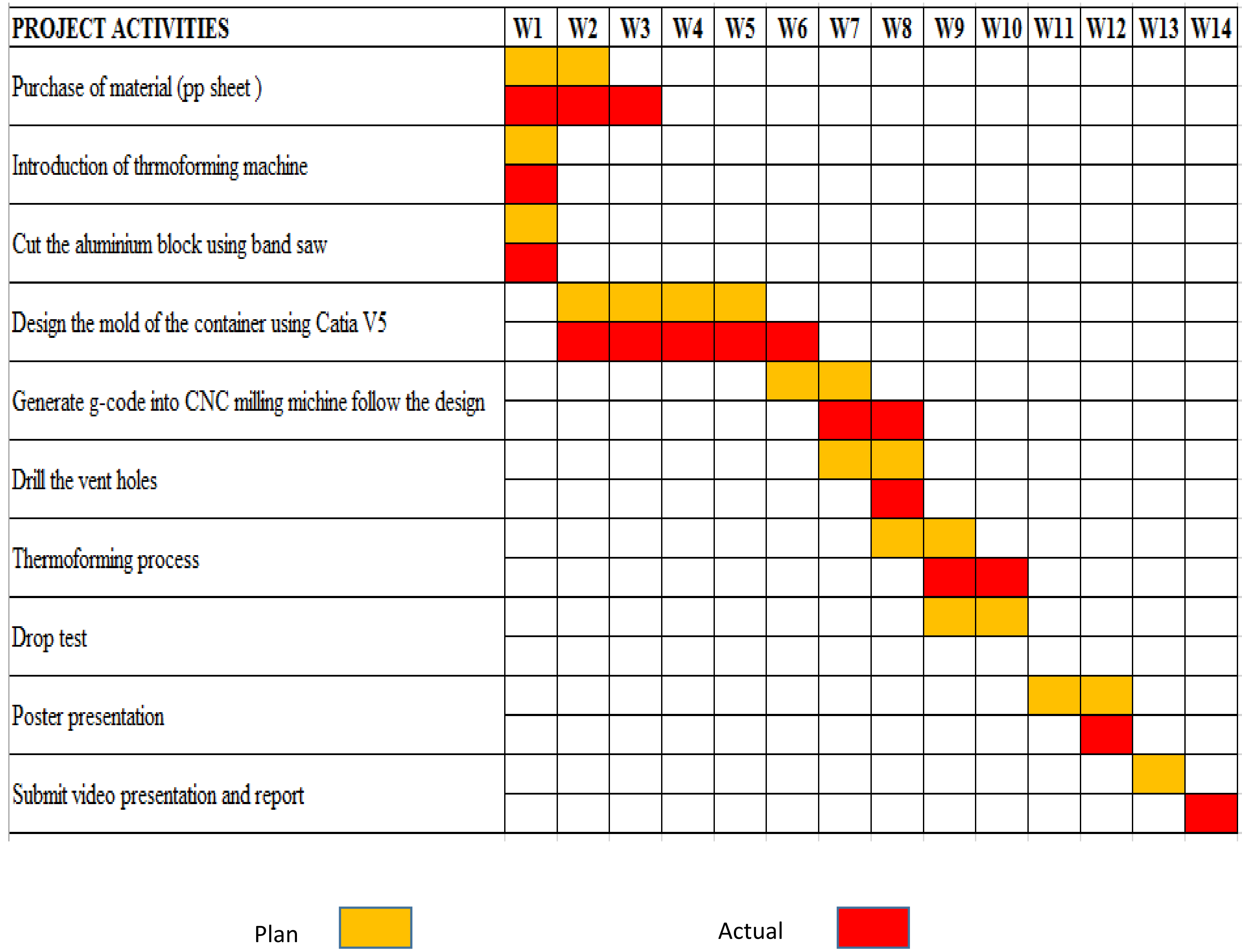
APPENDIX G

Temperature Sensor

APPENDIX H

Gantt chart FYP 1 and 2

TASK DESCRIPTION/WEEK		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1 BRIEFING	Plan	■													
	Actual	■													
PLANNING THE FYP1 FLOW	Plan		■												
	Actual		■												
READ THE JURNAL AND THE INFORMATION ABOUT THE PROJECT	Plan		■	■											
	Actual		■	■	■										
SUBMIT FYP 1 EXECUTIVE SUMMARY	Plan				■										
	Actual				■										
SUBMIT MILESTONE 1:INTRODUCTION	Plan					■									
	Actual					■									
SUBMIT MILESTONE 2:LITERATURE RIVIEW	Plan						■	■	■	■	■				
	Actual										■				
SUBMIT MILESTONE 3:METHODOLOGY	Plan										■	■			
	Actual											■			
PREPARE SLIDE PRESENTATION	Plan												■	■	
	Actual													■	
FINAL PRESENTATION	Plan														■
	Actual														■


PROJECT ACTIVITIES
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
Purchase of material (pp sheet)
Introduction of thrmoforming machine
Cut the aluminium block using band saw
Design the mold of the container using Catia V5
Generate g-code into CNC milling michine follow the design
Drill the vent holes
Thermoforming process
Drop test
Poster presentation
Submit video presentation and report
Plan
Actual