DESIGN OF THERMOFORMING PROCESS FOR PETG PART

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DESIGN OF THERMOFORMING PROCESS FOR PETG PART

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
B.Eng (Hons) Engineering in Manufacturing Engineering

Faculty of Manufacturing Engineering
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JUNE 2016

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SPECIAL DEDICATION

Dedicated to my beloved parents

MOKHZAN BIN CHE MOOD

SAIRA BINTI AB RAHMAN

and

My supervisor

ASSOCIATE PROF DR. ABDUL AZIZ BIN JAAFAR

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ABSTRACT

This project focuses on the drape forming process. The process involves draping a hot plastic sheet over a mold of the desired shape and allows the plastic to cool and harden to take shape. Aluminum of mold had been designed by using computer-aided design and simulated in CATIA V5R21 software. Venting line act as an air flow during thermoforming process and it was applied in this experiment. There were two types of mold had been machined which truncated semi-hemisphere mold with rectangular pocket (TSMRP) and circle pocket (TSMCP). CNC Milling Machine and EDM Wire cut were used to machined the thermoforming mold. Both of them had tested with PETG plastic sheet by using drape forming machine with constant temperature 180^{o}C and pressure 20kpa. The data of thickness after forming process proved that the first touched of plastic sheet to the mold was produced the highest thickness while final touched had produced lowest thickness. Beside that, the when the area of deformation plastic sheet was higher, the thickness was lower.

ABSTRAK

Projek ini memberi tumpuan kepada proses membentuk drape itu. Proses ini melibatkan draping lembaran plastik panas di atas acuan bentuk yang dikehendaki dan membolehkan plastik sejuk dan mengeras terbentuk. Aluminium acuan telah direka dengan menggunakan reka bentuk bantuan komputer dan simulasi dalam perisian CATIA V5R21. Pembolongan garis bertindak sebagai aliran udara semasa proses termopembentukan dan ia telah digunakan dalam eksperimen ini. Terdapat dua jenis acuan telah dimesin yang dipenggal acuan separuh hemisfera dengan poket segi empat tepat (TSMRP) dan bulatan poket (TSMCP). CNC mesin pengilangan dan EDM Wayar memotong digunakan untuk dimesin acuan termopembentukan itu. Kedua-dua mereka telah diuji dengan helaian plastik PETG dengan menggunakan drape membentuk Mesin dengan 180oC suhu dan tekanan 20kPa. Data yang ketebalan selepas proses membentuk membuktikan bahawa yang pertama menyentuh lembaran plastik acuan dihasilkan ketebalan tertinggi manakala akhir menyentuh telah menghasilkan ketebalan rendah. Selain itu, apabila kawasan lembaran ubah bentuk plastik adalah lebih tinggi, ketebalan adalah lebih rendah.

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
EDM	Electric Discharge Machining
PETG	Polyethylene Terephthalate Glycol
TSMRP	Truncated Semi-hemisphere Mold Rectangular Pocket
TSMCP	Truncated Semi-hemisphere Mold Circle Pocket

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

There are many type of manufacturing process. One of them is thermoforming process where the plastic sheets are formed with the application of heat, pressure and vacuum to a mold. Aluminum is one of the materials that use for mold.

Firstly, part is designed and it proceeds with the mold design by using CATIA V5R21. The plastic sheet is put horizontally over the mold surface and clamped with the holding device. Heater is a heating element that used to predetermine temperature for heating the plastic sheet. Temperature of the heater is maintained by the thermostat. When the plastic sheet softens with the application of heat, then it is pressed over the mold surface by using drape forming process. The softened plastic sheet will be form by following the mold shape and it is hold in place until it cools. The plastic part will open when the mold cavity is opened. As we know some of the plastic materials have low thermal conductivity, so air cooling is needed in order to make that rigid part quickly. Trim out the excess plastic sheet from the finish part.

Clamping unit, air cooling system, heaters, and mold are the basic of the thermoforming set-up. Here, there is a precaution to mold such as we need to take more attention to the mold surface like clean it after every cycle because it will cause the change shape to the plastic part after forming.

1.2 PROBLEM STATEMENT

In my project, I had made a research regarding the one of the thermoforming process which is drape forming process. To produce the plastic part which fully follows the mold shape by using drape forming process is not easy because it need to create venting hole or venting line to the mold design. Based on the journal, many ways they use to produce the actual shape of plastic sheet without any damage and the shape which follow the mold shape design. Therefore, venting hole is one of the methods used in industry to form a plastic sheet which follow the mold. For the female mold, plug is used to assist the forming so that the hot sheet follows the shape of the mold. While, venting line is also method that can use to form a plastic which will follow mold's shape without using a plug.

1.3 OBJECTIVE

This project is about the flow of thermoforming process. There are several objectives that should be achieved at the last of this project. The objective is as below:

a) To review engineering design process for engineering plastic part
b) To design thermoforming process
c) To produce plastic part by using drape forming process

1.4 SCOPE PROJECT

For this project, there are several scope of study which are:

a) To review engineering design process for engineering plastic part
b) To study regarding the features at the thermoforming mold
c) To design the part and mold of the thermoforming process by using CATIA V5R21

d) To fabricate the thermoforming mold by using milling machine & EDM Wire Cut
e) To produce a plastic part by using drape forming process based on the part and mold design

1.5 FLOW CHART

This project had been planned in the sequence in order to achieve the objectives. The flow chart is important to make sure all works concerning the project will be carried out as planned and smoothly. Figure 1.1 shows the process begins by refining the objectives and project background of the project. Research had been done by journal and reading material about project, this step is significant to make sure that project will run smoothly and to keep the project within its scope. Journal and reading material are review according to the project title and scope.

Procedure and methodology of the project are planned and recorded. Figure 1.1 shows the project flow chart. Whereas Gantt chart can be referred in appendices A.

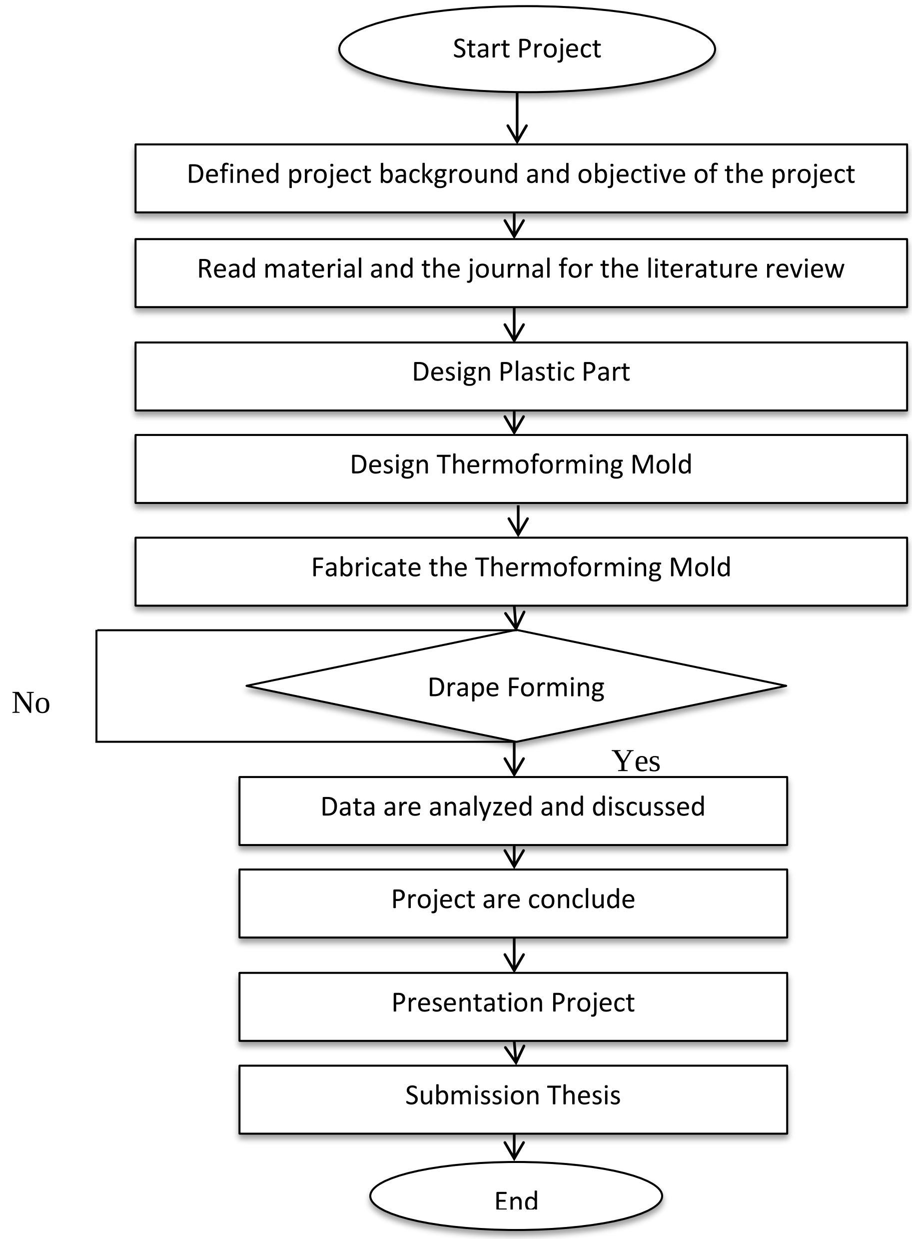


Figure 1.1. Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Thermoforming process is one of the manufacturing processes which widely used in the industry to produce shape plastic sheet. Thermoforming is one of the most common and the oldest methods of processing plastics materials. Plastic products are the major part in our daily lives. The process involves applying heat by using infrared heaters to make the plastic become soft and pliable for shaping the plastic sheet by air-tight clamping of the sheet's outside perimeter over a mold (Walczyk & Yoo, 2009) .

In plastic, there are two categories like thermoset and thermoplastic. For the thermoplastic, it defines as the plastic can be heated and shaped many time without changing the characteristic. But it difference with the thermoset that can only use only one time because it cannot be reshaped after heating. Thermoforming is generally concerned with thermoplastics (James, 2012).

2.2 THERMOFORMING PROCESS

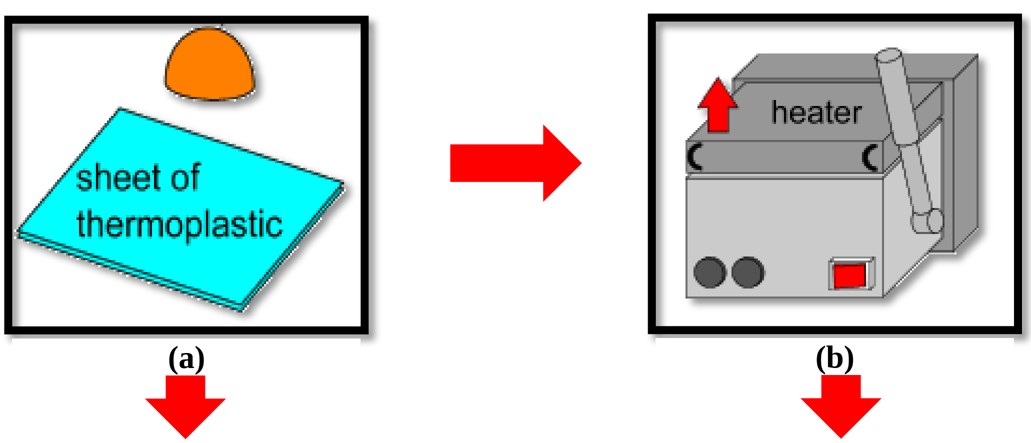
Thermoforming is the process of heating a plastic sheet to its softening point, stretching it over or into a single-sided mold, and holding it in place while it cools and solidifies into the desired shape. The plastic sheet is clamped into a holding device and heated by an oven using either convection or radiant heat until it is softened. The sheet is then held horizontally over a mold and pressed into or stretched over the mold using vacuum pressure, air pressure, or mechanical force. The softened sheet conforms to the shape of the mold and is held in place until it cools. The excess material is then trimmed away and the formed part is released. Excess material can be reground, mixed with unused plastic, and reformed into thermoplastic sheets. (Walczyk & Yoo, 2009)

Beside that, thermoforming is a plastic fabricating process which involves heating sheet plastic and forming it over a male or female mold. The two basic types of thermoforming processes such as vacuum forming and pressure forming, make plastic thermoforming a broad and diverse plastic forming process. Thermoformed plastics are ideally suited for automotive, consumer products, packaging, retail and display, sports and leisure, electronics, and industrial applications.(Walczyk & Yoo, 2009)

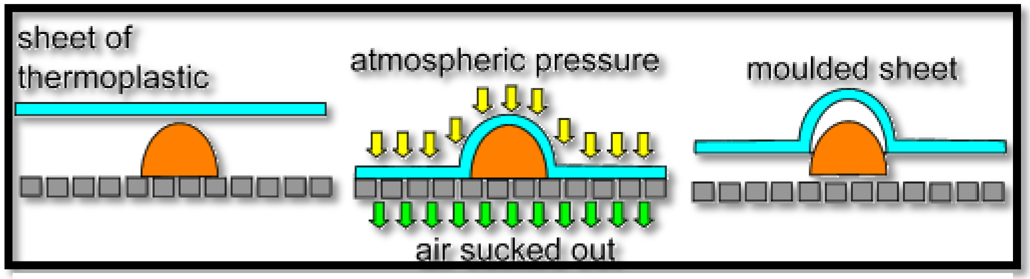
2.2.1 Vacuum Process

Vacuum process is one of the processes that involve mold and plastic sheet by forming thermoplastic sheet into three-dimensional shapes through the application of heat and pressure. Beside that, vacuum process refers to all plastic sheet techniques including drape forming which one of the most popular method. During vacuum process, plastics sheet will heat until it become soft and pliable. After that it will placed over a mold whether male or female mold and drawn in by a vacuum till it produce a part on the desired shape.(Walczyk & Yoo, 2009)

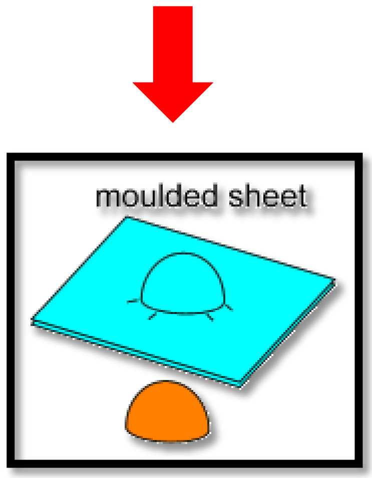
Below shows that the simple step of the vacuum process:



(a) **(b)**



(c)



(d)

Figure 2.1. Vacuum Process

Source : http://www.the-warren.org

2.2.2 Pressure Forming

Pressure forming process quite similar with the vacuum process, but it needs more additional pressure, that need pushed the sheet plastic into the shape of the mold. Normally, pressure greater than atmospheric (14.7 psi) are needed to push the plastic sheet into more intimate contact with the mold surface (Multifab, 2009). In addition, pressure forming produces more detail which allowing for sharp corners, undercuts and surfaces that are not as easy as vacuum forming process. Figure 2.2 shows the process of pressure forming process.

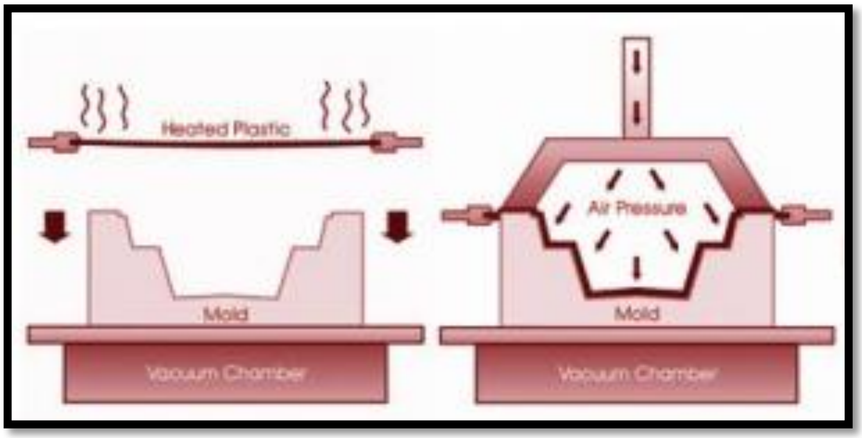


Figure 2.2. Pressure Process

Source : http://pressureforming.co.uk/pressure-forming/

2.2.3 Twin Sheet Forming

Twin sheet forming is the process which separate mold on the top and bottom platens. Two sheets of plastics essentially simultaneously by using pressure and vacuum forming process. Moreover, between the two sheets, twin sheet forming can be produce with different coloursand surface finish and the thicknesses. Figure 4 show the process on how two sheets of plastic are produced by using twin sheet forming process (Howell, 1975)

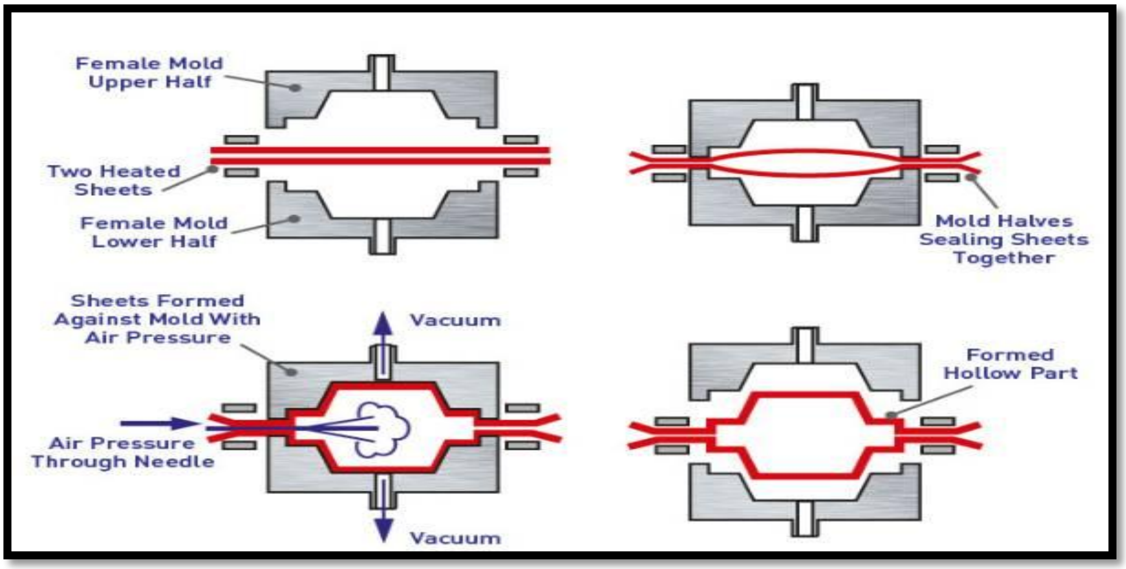


Figure 2.3. Twin Sheet Forming

Source : http://www.cannonergos.com

2.3 FEATURES OF PART DESIGN

To prevent the plastic part from damage, there are a few features that we need to follow during mold design so that the plastic part will me produce by following the mold shape.

2.3.1 Draft Angle

Draft angle is one of the important features that must add to every side of the mold. This is because, after the vacuum process occur, the plastic part will be easy to remove from the mold base on the draft angle. Basically, the draft angle range for male mold is 1^{o} to 5^{o} per side. While for female mold is 1^{o} to 3^{o} per side (Tam & Chan, 2007). Furthermore, female mold is not necessarily requiring any draft angle which suggested 2^{o}. While for the male mole must have draft angle in order to allow the part to be released. Crystalline material which has higher shrink material may require more than 5^o. but for the amorphous material, it only need 3^o (Klein, 2009)

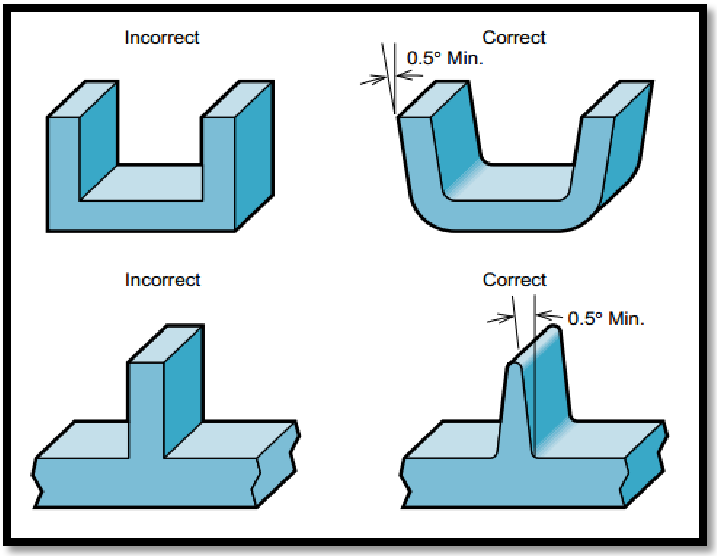


Figure 2.4. Draft Angle

Source : (Gruenwald, 1995)

2.3.2 Draw Ratio

To develop the desired shape, the heat-softened plastic sheet is stretched or draw by the thermoforming mold. When stretched process occur, the thickness will be decrease and the surface area is increase (Tam & Chan, 2007) . Draw ratio means the ratio of the surface area of sheet after to before forming like the sharp edges that will lead to a high draw ratio. Thermoforming features will easier to form when the draw ratio is low. Below shows the formula how to calculate draw ratio as in Eq. (2.1):

$$\textbf{Draw Ratio} = \frac{\textbf{depth of part}}{\textbf{width of part}} \tag{2.1}$$

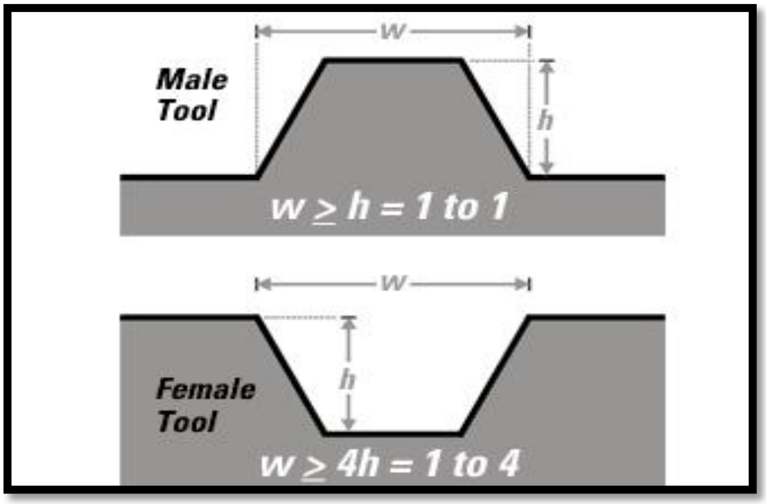


Figure 2.5. Drawn Ratio

Source : http://www.sabic-ip.com/gep/Plastics/en/ProductsAndServices/DesigningUsingIMDDetail/forming_tool.html

2.4 MOLD DESIGN IN THERMOFORMING

2.4.1 Type of Mold Design

Two type of mold that we can use in the vacuum process like male (plug or positive) and female (cavity and negative) mold. Male mold has one or more protrusions over which the heated plastic sheet is drawn to form a shape, while female mold has one or more cavities into which the heated sheet is drawn to form a shape. Moreover, the wall thickness of the plastic part which forms on a male mold is greater at the top of the plastic part. then, for the female mold, the wall thickness of the plastic part thermoformed is greater around the flange (Gruenwald, 1995). Here, we can see that the difference position in the same process between male and female mold.

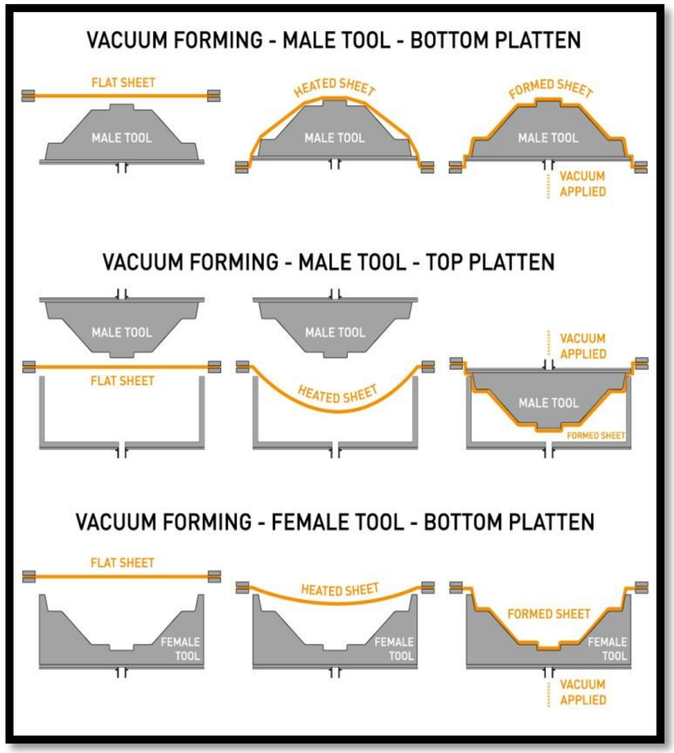


Figure 2.6. Male & Female mold in vacuum forming process

Source : http://warringah-plastics.com.au/services/vacuum-forming/

2.5 MOLD MATERIAL

There are many types of materials for mold. For example, aluminum, wood, steel have been used successfully in making mold for vacuum process. Normally, aluminum is used as a material for mold in the thermoforming. It is because aluminum is light, is relatively inexpensive, it is easy worked and very thermal conductivity.

2.5.1 Wood mold

Wood has different shrinkage rates across the grain versus grain that cause the grain should run parallel. Beside that, wood mold can be coated with an epoxy resin, then sanded, buffed, and polished which can improve the stability by preventing the absorption of moisture by the wood. Generally, wood is the best fabricated hardwood, glued with a thermosetting glue, and sealed with the paste filler (Gruenwald, 1995) .

2.5.2 Aluminum mold

There are two ways on how the aluminum mold can be made. First is by fabricating the aluminum plate stock and machined to proper dimensions and finished part. Second, is made by casting the aluminum, then machine and finishing it. High polish will give the best surface that can be texture. The characteristic of the aluminum mold is the excellent heat conductor and permits rapid heating and cooling for fast cycle (Gruenwald, 1995).

Figure 2.7. Wood and Aluminum Mold

Source : (Gruenwald, 1995)

2.6 TYPE OF PLASTIC SHEET

Amorphous is the one of the best plastic material that generally used in the thermoforming process. There are several examples of the amorphous such as ABS, Polystyrene, polycarbonate and PVC. About 80% of all plastics thermoformed are amorphous (James, 2012)

Published literature was suggested for the forming temperature windows of amorphous is 100^{o}C or more, but it depends on the plastic sheet sag and thermal stability, part geometry mold and plug design and extent of required part detail for the practical forming window (Ashter, 2013).

2.7 HOW A SHEET STRETCHES

2.7.1 Forming into a mold vs. Forming onto a mold

There two type of mold for thermoforming process. First is forming into a mold cavity which is female mold, and second is forming onto a mold that we called it as male mold. At first, when the mold cavity is used, the plastic sheet will stretch into the open cavity then it will lay on the mold surface. Usually, the plastic sheet that contact with the mold surface will not stretch any further. Because the sheet which is free become thinner as it is stretched to the bottom mold. As a result, the plastic part will thinnest at the bottom and thickest at the rim. At the corner is the region of the part where the wall meets the bottom.

For the male mold, we considered it as truncated cone where the first sheet is touch the mold at the bottom of the part being form. The mold is pushed into the sheet, and then the sheet stretches between the bottom of the mold and the clamp. The sheet thickness is normally quite uniform, if the plastic sheet does not touch the sides of the mold till the mold is completely immersed. As a result, the part will be thinnest at the rim and thickest at the bottom, if the plastic sheet touches the sides of the mold like the mold is pushed into the sheet (James, 2012).

2.7.2 Forming "Up" vs. Forming "Down"

Forming "Up" vs. forming "Down" mean, when the mold is placed above the sheet, the mold is immersed in the plastic sheet and the plastic part is formed up into or onto the tool. Then, when the mold is placed below the plastic sheet, the plastic sheet sags onto or into the mold and the plastic part is formed down into or onto the tool. In thin-gauge thermoforming, female mold has advantages with forming up. This is because gravity is assists when releasing parts from muti-cavity tooling. Beside that, the part is properly oriented for in-line trimming (James, 2012)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will explain about the project flow diagram, designing process, material selection and fabrication process. It is important to follow the project flow diagram in order to assure that the process of this research is follow from the beginning until the end of the project. It is also determined the troubleshoot the problem during the project running. All the process and method used is based on the earlier research will compromise. Figure 3.1 shows the process flow chart of this project.

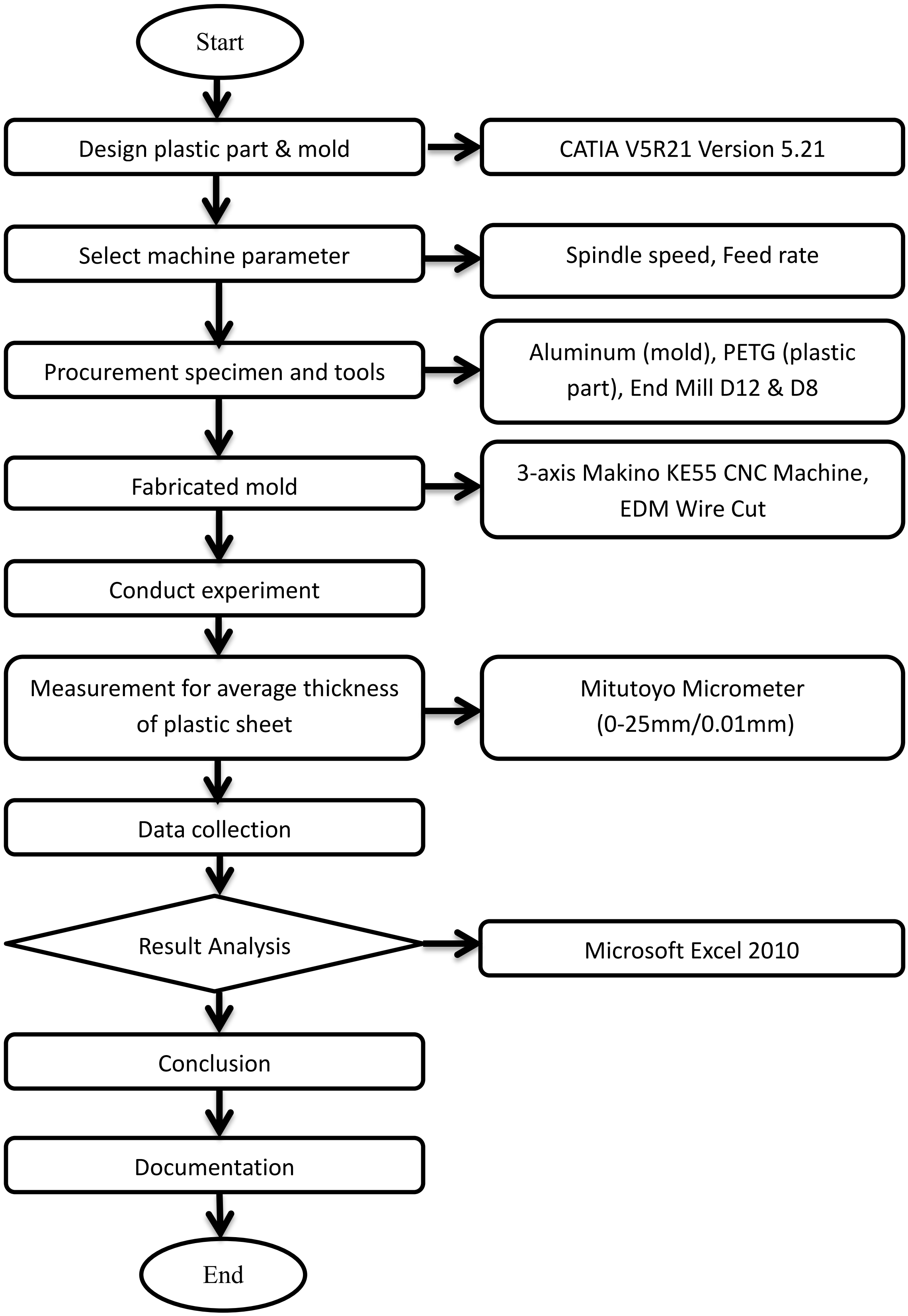

Start
Design plastic part & mold
CATIA V5R21 Version 5.21
Select machine parameter
Spindle speed, Feed rate
Procurement specimen and tools
Aluminum (mold), PETG (plastic part), End Mill D12 & D8
Fabricated mold
3-axis Makino KE55 CNC Machine, EDM Wire Cut
Conduct experiment
Measurement for average thickness of plastic sheet
Mitutoyo Micrometer (0-25mm/0.01mm)
Data collection
Result Analysis
Microsoft Excel 2010
Conclusion
Documentation
End

Figure 3.1. Process Flow Chart

3.2 PROCESS FLOW DETAIL

Based on the project flow diagram above, the project was started with collecting information which relate with the project like in journal, books, and internet to obtain a literature review and research regarding the thermoforming process. In this part, it was focused more on design part and mold, drape forming process and the finish part either the plastic sheet will follow the shape of mold. This literature review will guide to decide the right decision before the design and fabrication go on.

After collecting all the relevant information, the project undergoes project methodology. This part consists of design process, material selection and fabrication process. Design consideration has been made after several part designs sketched and one of the part designs had been chosen. Then the mold design will be follow the part design for thermoforming process. Part and mold were designed by using CATIA V5R21.

When the best part design was chosen, the next process is collecting information for designing the mold design to get the actual shape for finish plastic part after drape forming process. During mold design process, there are several features that need to take more attention likes drawn ration, draft angle, and fillet. This is because, mold design will play an important role to the finish part. Later, during the drape forming process, mold design will be affect the plastic sheet that cause the shape of plastic part either the shape will follow the mold or not. Machine parameter very important for designing a product. Constant parameter was selected which were 2500rpm for spindle speed and 20mm/s for feed rate. After completing the mold design, the mold was fabricated by using 3-axis CNC Machine (Makino KE55) and EDM Wire Cut.

Molds were fabricated with two types of pocket like round and rectangular pocket which were act as a female mold. Therefore, in one mold there are two types of mold for such as female and male mold. Venting line was created to both of molds manually by hacksaw with minimum material thickness of 1.1mm for aluminum mold.

After creating the venting line for both molds, process was continued with the drape forming process based on the mold that fabricated before. Drape forming process was function by using constant temperature like 180^0C for heating plastic sheet. When the process was done, the thickness of plastic sheet after forming was measured by using micrometer. All of the data was collected and the result was analyzed. Conclusion from overall data and research was documented in report.

3.3 DESIGN PROCESS

The mold design must be compliance with several aspects. The design consideration must be done carefully so the design can be fabricated and the plastic part will be produce smoothly that will follow the mold shape. The aspects that must be considered in designing are:

- **Draft Angle** : Must follow the actual draft angle for male mold design for thermoforming process so that there are no damage occur to the plastic sheet after vacuum process
- **Fillet**: Every edges of at the mold design must apply the fillet for the maximum strength and serviceability.
- **Venting Line:** In thermoforming process, there must be creating venting line so that it will reduce air trap during the process.

3.3.1 Sketching Idea

The ideas of designing the part and mold design are for sketching to get the earlier description. From the existing ideas, one of the sketching had been chosen to be considered as the final ideas. A few of them are:

3.3.1.1 Idea A

Idea A shows below is the first sketching of mold design which has a pocket in the middle of the hemisphere. The dimension of the rectangular pocket is 30 x 15 mm and the depth of the pocket is 30 mm similar with the hieght of the hemisphere. The diameter of the hemisphere is 60mm and the diameter of the base is 80mm. this idea is not selected because the rectangular pocket is too small for the drape forming process that cause some problem like the shape of the plastic sheet will not follow the mold design beside the mold do not have draft angle at the hemisphere and base.

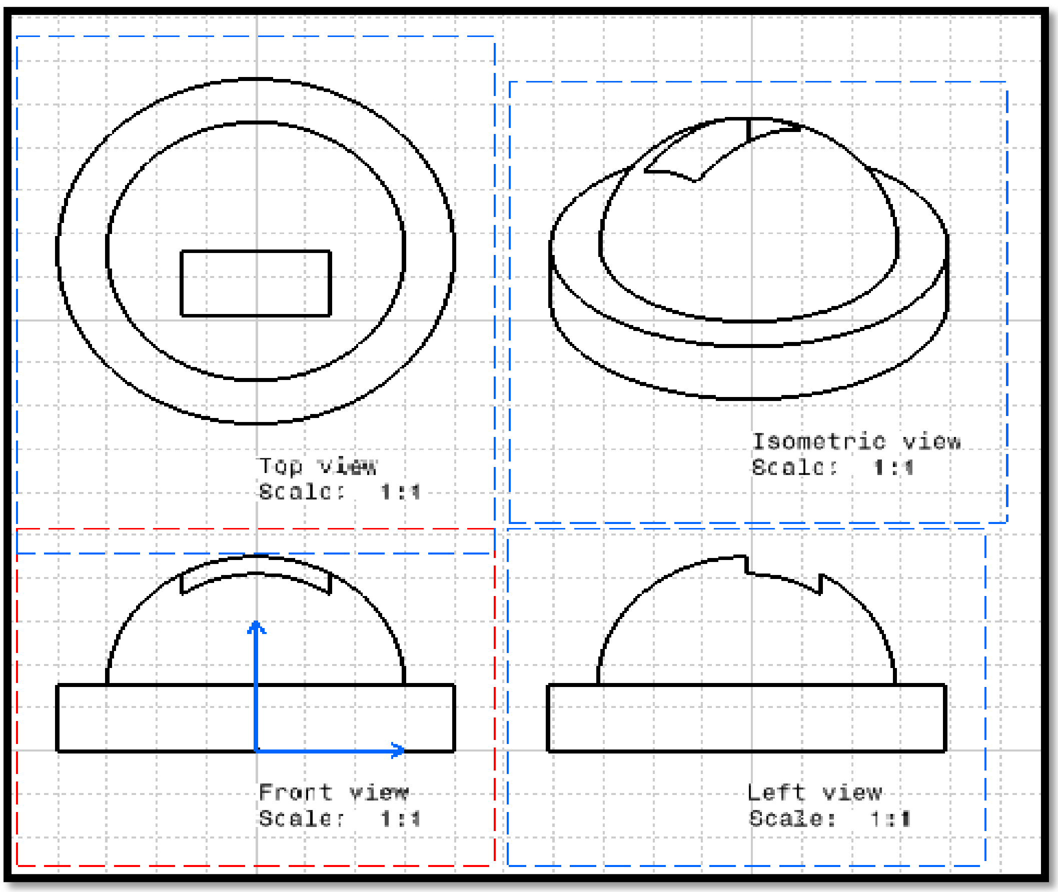


Figure 3.2. Design of idea A

3.3.1.2 Idea B

Idea B was designed base on the idea A which adjusting the surface area of the pocket at the middle. Figure 3.3 shows the difference sketching compare to idea A. For the diameter of the pocket in idea B is 40x30 mm. Beside that, the diameter of the hemisphere is changed become 80mm and the diameter of the base is same like idea A. In idea B there is an addition feature in the design which is fillet. Fillet is modeled to round off the edges and the corners of the mold design. The radius of the fillet in the idea B is 1^{o}.

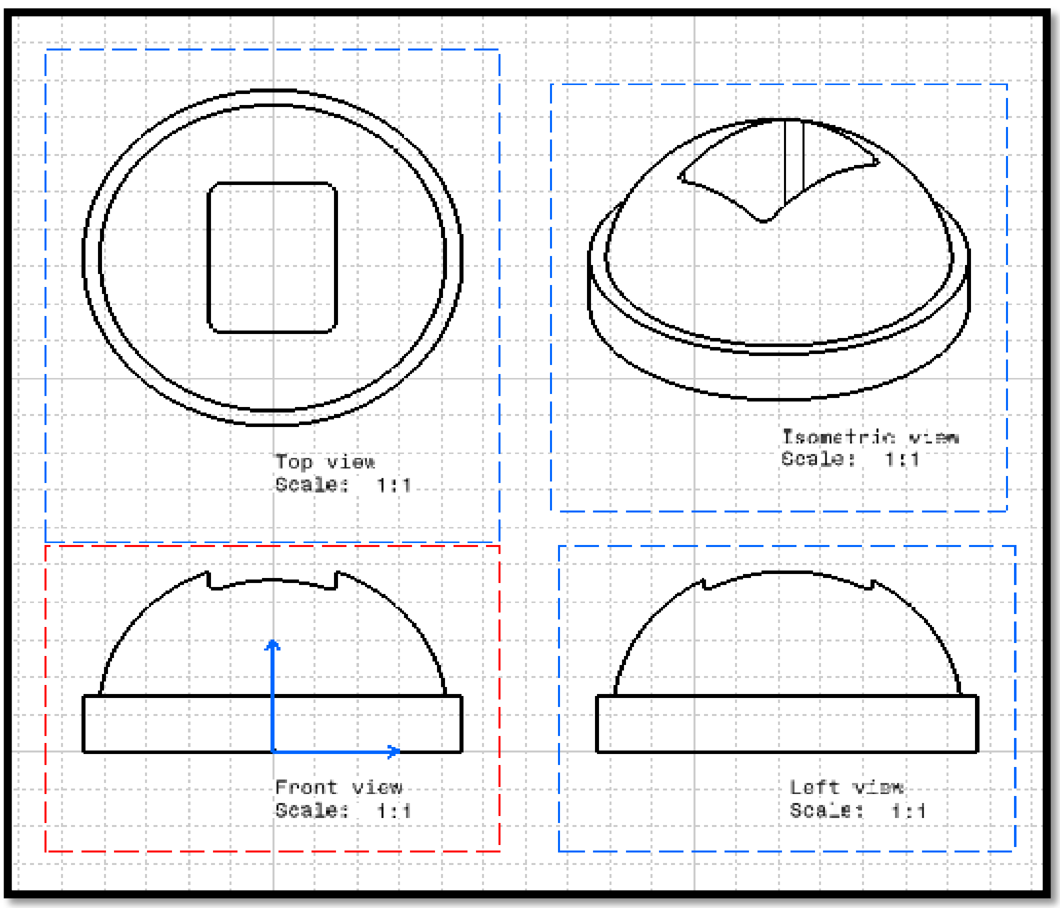


Figure 3.3. Design of Idea B

3.3.1.3 Idea C

Figure 3.4 shows the design of idea C which difference compare with the both idea before which are idea A and B. In idea C there are a few features is added to the mold design like fillet and draft angle. The function of the draft angle to all sides of the mold design is it easy to remove the finish part which is plastic sheet after vacuum process from the tool once they have been form. Generally, the range of the draft angle of the male mold is 4^{o} minimum. Then, for the idea C below, the draft angle is 5^{o}. Besides, the radius of the fillet at all edges likes at the bottom of hemisphere and at the upper of base are both same which is 1^{o}. Then, the upper of the hemisphere is trim to avoid the sharp corner so that the plastic sheet will not damage during vacuum process.

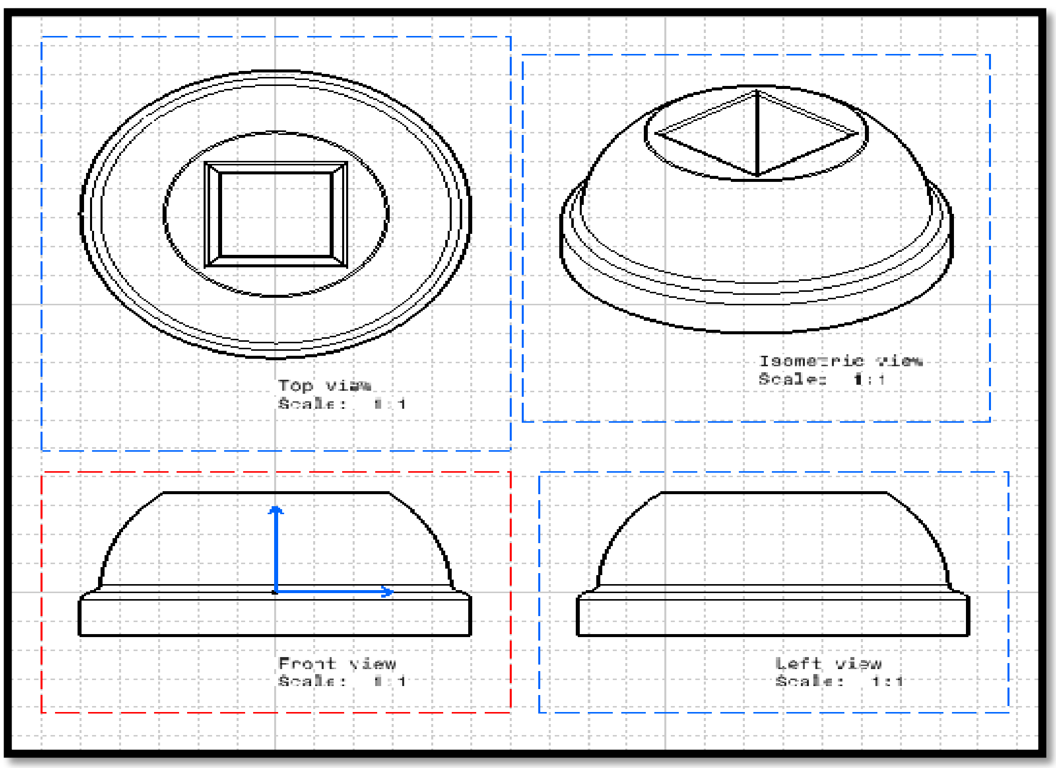


Figure 3.4. Design for idea C

3.3.1.4 Idea Selected

Below shows the selected idea because there are complete features which follow the quide of the thermoforming process. In the thermoforming process, there are some features that we need to follow for designing the mold design so that the shape of finish part will be produce by following the mold design. For this idea selection, it quite similar with the idea C. The difference here is adding the draft angle at the base. Beside that, another design of mold was added with difference pocket as shown in Figure 3.5 for circle pocket. The purpose of designing two difference pockets is to see the function of venting line which created to the mold. In thermoforming process, there were some guidelines for draft angle male and female mold like 5^0 for female mold and 10^0 for male mold.

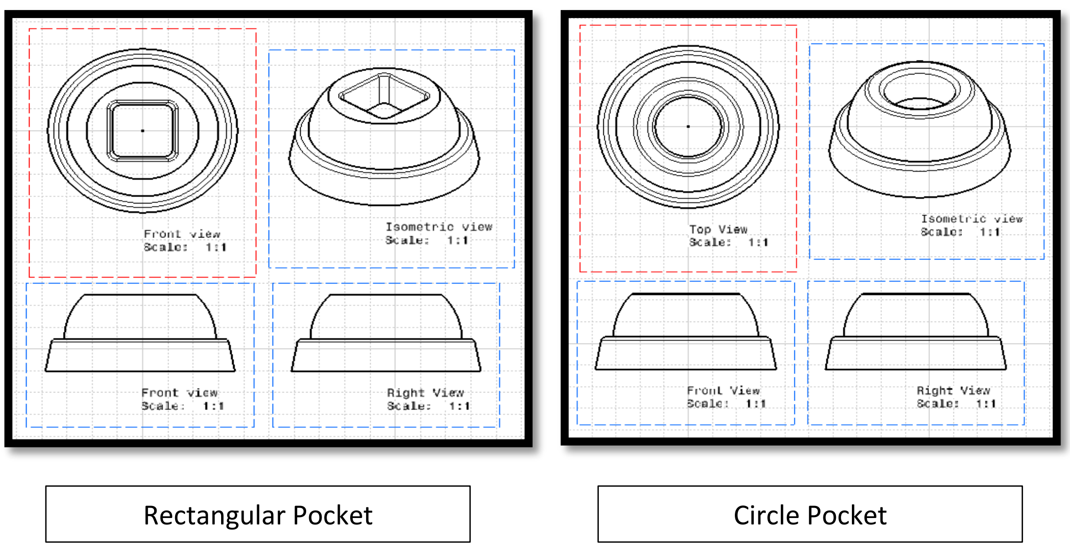


Figure 3.5. Design of selected idea

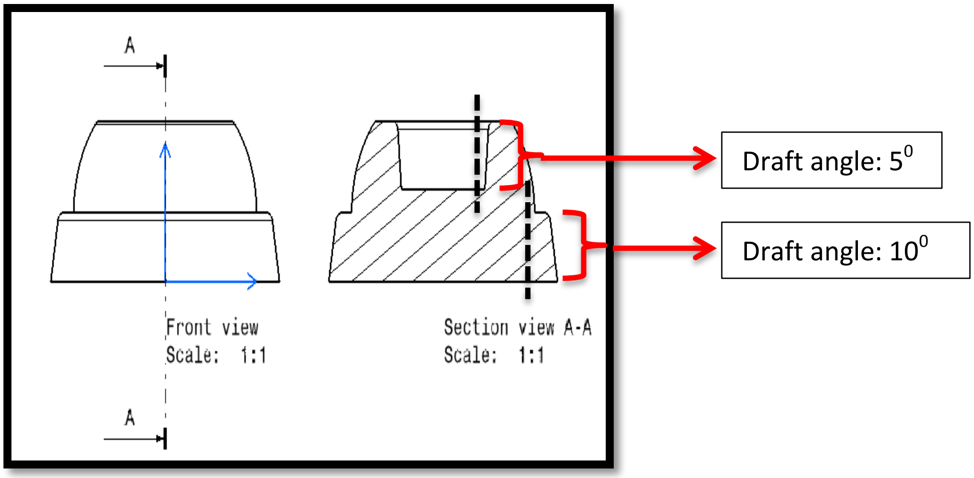


Figure 3.6. Draft angle for male and female mold

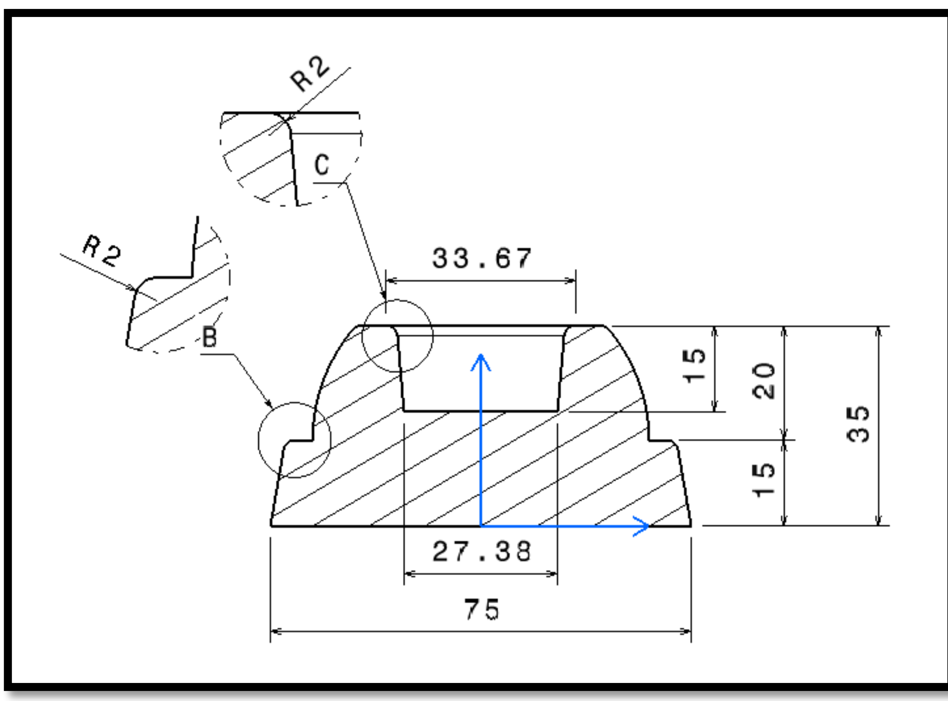


Figure 3.7. Dimension of selected design

Figure 3.6 show the section view A-A which is the dimension of the selection mold design with complete features such as fillet and draft angle. The height of the base is 15mm and the radius of the hemisphere is 43^{o}. As we can see at the figure above, there are different radiuses of fillet shown. Beside that, adequate fillet or outside corner radii are essential for maximum strength and serviceability. The range of the radius of fillet should be at lease similar to the wall thickness of the plastic sheet and never less than 0.8mm. an ideal fillet radius would be more than ten times the wall thickness (Gruenwald, 1995).

3.4 MOLD DESIGN

For mold design, I used to apply the assemble concept which is separating hemisphere and base part. Figure 3.8 shows the venting line which created to the mold and the angle at the shape corner which is 90^{0}. Venting line act as air flow, while fillet will reduce the defect to plastic part during drape forming process occur. Figure 3.9 shows the variation of venting line which created to both rectangular and circle pocket of mold design.

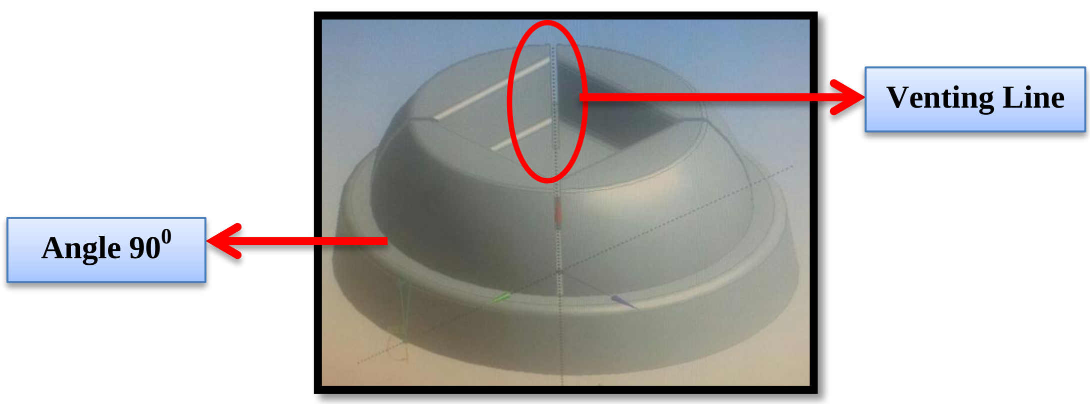


Figure 3.8. Venting line and sharp corner with angle 90^{0}

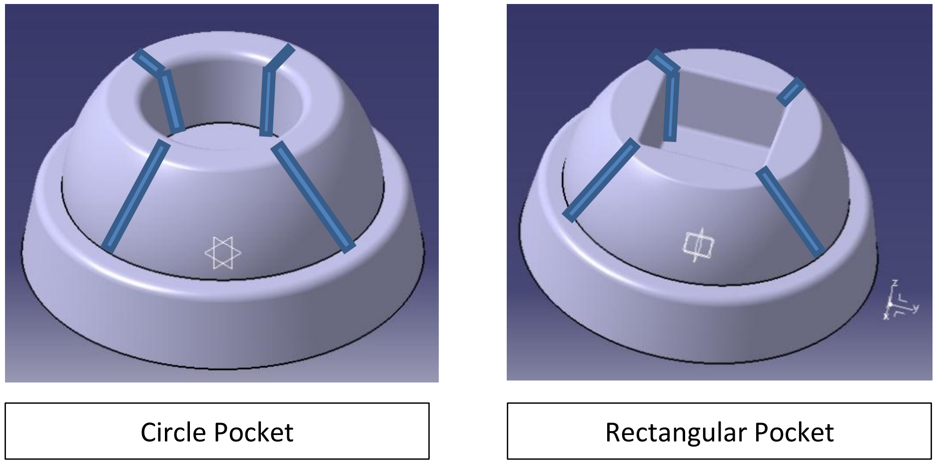


Figure 3.9. Variation of venting line to mold design

3.5 SOFTWARE

For this project, 3D software, CATIA V5R21 was used for designing the thermoforming mold design. This software was chosen for my project because I have the basic knowledge regarding the CATIA V5R21 that I gain from my first year study. Beside that, this software is the main software that used at the Faculty of Manufacturing Engineering. Furthermore, it easy for me to complete the simulation likes NC coding before running to the machine to fabricate the thermoforming mold. This software was compatible with CNC milling machine which simulated in advance machining program.

Figure 3.10. CATIA V5R21 version 5.21

3.6 MACHINE

3.6.1 CNC Milling Machine

To fabricate the thermoforming mold, 3-axis Makino KE55 CNC milling machine was used. Milling machine is one of the machines that can fabricate any material product like stainless steel, aluminum, sheet metal and so on. CNC milling machine have 3-axis which can move with difference axis like X, Y, and Z direction. This machine has capability to achieve spindle speed up to 4000 rev/mm. Table 3 shows the specifications of CNC Millling Machine.

Figure 3.11. 3-axis Makino KE55 CNC Milling Machine

Table 3.1 : Makino KE55 Basic Specifications

Machine type	**Vertical**
Control	CNC
Number of Axis	3
X axis Travel	550mm
Y axis Travel	320mm
Z axis Travel	350mm
Spindles	1
Motor Power	5.6kW
Maximum spindle speed	4000RPM
Maximum Cutting Feed	5000mm/min
Maximum Load	200kg

3.6.2 EDM Wire Cut

Electric Discharge Machining (EDM) Wire Cut was used for cutting mold between hemisphere and base part as shown in Figure 3.12. Table 4 shows the specifications of EDM Wire Cut.

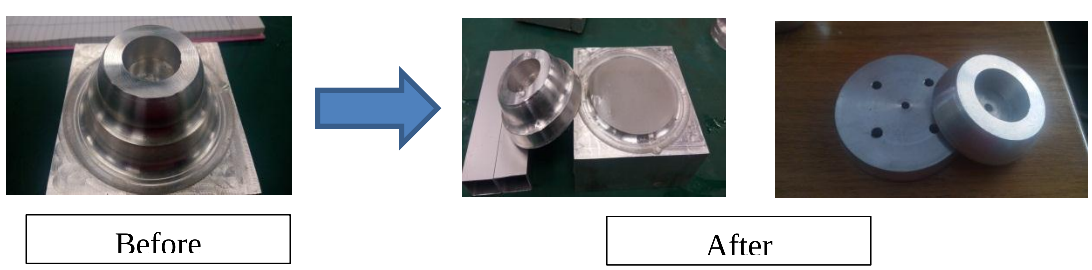


Figure 3.12. Aluminum mold before and after cutting by using EDM Wire Cut

Figure 3.13. Electric Discharge Machining (EDM) Wire Cut

Table 3.2: EDM Wire Cut Basic Specifications

X-axis Travel	350mm
Y-axis Travel	250mm
Z-axis Travel	220mm
U, V axis Travel	80 x 80 mm
Wire Diameter Range (min ~ max)	0.10 ~ 0.30 mm
Work Tank Dimensions (W x D)	810 x 650 mm
Maximum Workpiece Weight	500kg
Distance from Floor to Table Top	900mm
Machine Tool Dimensions	1895 x 2180 x 1960 mm
Machine Weight	2400kg

3.6.3 Hobby Vacuum (Drape Forming Machine)

Hobby Vacuum Machine is a simplified, version of thermoforming process, where a plastic sheet is heated to a forming temperature, stretched onto mold, and forced against the mold by a vacuum source. The type of vacuum source that use for hobby vacuum is Vacuum Cleaner Easy Samsung with 1800 Watt with dimension net is 233mm x 370mm x 273mm (WxHxD) and weight net is 4.0kg. Beside that, material that suitable for vacuum forming is conventionally thermoplastics. Hobby vacuum is often used in low-level technology classes for an easy way to mold.

Figure 3.14. Hobby Vacuum (Drape Forming Machine)

3.7 MATERIAL

3.7.1 Thermoforming Mold

For the material of thermoforming mold, I choose to use aluminum because it is easily worked, light, not expensive and have very high thermal conductivity. When using the aluminum workpiece, the forming forces against the finished mold are low. Beside that, aluminum is most commercial thermoforming mold. Furthermore, aluminum workpiece is already provided at the faculty.

3.7.2 Plastic Part

Generally, in the thermoforming process, there are two types of plastic sheets such as amorphous and semi crystalline. For my project, I choose to use Polyethylene Terephthlate Glycol (PETG) for the material of plastic part. Beside that, PETG plastic sheet are approved for food contact applications and at low temperature, it have good impact resistance. Moreover, this plastic sheet has outstanding thermoforming properties, good mold reproduction without the need for pre-drying, combining low energy consumption, extreme draw ratios, and short production cycles.

3.8 EXPERIMENTAL METHOD

Step 1: Design Thermoforming Mold

1. Design part and mold by using CATIA V5R21
2. Select the best design
3. Proceed with the simulation for NC Coding
4. Choose suitable parameter for fabricating mold
5. Generate NC coding

Step 2: CNC Milling Machine

Power up machine

1. Turn on power source
2. Turn on Main Power Switch
3. Release Emergency stop button
4. Turn on air supply valve

CAUTION:

a. Check air pressure in set to 5 kg/cm^3 (71 PSI)

b. Check air lubricator oil level

c. Check automatic lubricator air level

d. Check air dryer id ON (If this option is available).

Warming up the machine

1. Push (REPPOS) soft key at the General Mode screen
2. Select Automatic Feed Lever: X+, Y+, Z+
3. Push MEMORY button at the Operator Panel
4. Push PROG button at the Operator Panel
5. Push RESET button at the Operator Panel
6. Call program: input O1000 (Dry run Program)
7. Push O SRH button at the Operator Panel
8. Confirm the program OK
9. Push CYCLE START button at the Operator Panel
10. Rotate the Rapid Feed Override button to 25%
11. Rotate the Cutting Feed Override button to 100%

Fabricate Mold

1. Clamp the aluminum workpieces (100 x 100 x 50 mm) specimen on 3-axis CNC Milling Machine. (Make sure worktable is free from burrs and dirt so the it will not affected to the workpieces when program on running).
2. Set up machine to NC program (make sure rotate Rapid & Cutting Feed Override to 0% for safety)
3. Transfer coding to milling machine (make sure PC was connected to machine for NC Coding programming)

4. Push CYCLE START button at the Operator Panel
5. Rotate Rapid Feed Override to 25% and Cutting Feed Override to 30%
6. Mold start running

Table 3.3: Parameter of fabrication mold

Spindle speed	2500RPM
Feed Rate	20 ~ 30 mm/rev

Step 3: Electric Discharge Machining (EDM) Wire Cut

Power up machine

1. Switch on Main Power Supply
2. Switch on Machine Main Switch
3. Press SOURCE ON button
4. Press POWER ON button

Home Position

1. Press ENT button: Z+, X-, Y-, U-, V- (make sure that Z, X, Y, U and V sign is correct)
2. Press MOVE at screen
3. Change Coord. System from 54 to 55
4. Press U and V at screen
5. Press ENT button (the Top part and the Bottom part are now aligned).

Threading Wire

1. Press Z- between top and bottom part within 8cm ~ 15cm until the height
2. Press Threading II button

Setting Up Graphics Cutting Path

1. Press Edit
2. Press Load
3. Select File Name (Aluminum Mold)

4. Press OK
5. Press Graphics at screen side
6. Set No. Contour = 50
7. Press Draw
8. Press Save

Material Set Up

1. Place the material (Mold) on the base (use ‘L’ to align the mold)
2. Tight the mold using Allen Key size 6mm

Setting Material Origin

1. Press Manual
2. Press Appr. Face
3. Press 1 Axis
4. Press X
5. Input Wire Diameter = 0.25
6. Input Inverted Value = 1.0
7. Click ABS
8. Press ON on Coord. 0 Set
9. Move the wire close to the edge of the material in X-axis
10. Press ENT
    * Repeat step 1-10 for Y-axis
11. Press MOVE, press X, (Input value = -10.0), Press Y, (Input value = 10.0), Press ENT

Start Cutting

1. Press Z- until the gap between material and Top part within 2~3 mm
2. Press MOVE, Press X, (Input value = -5.0), Press Y, (Input value = -15.0), Press ENT
3. Press RUN at screen side
4. Click HOME at keyboard
5. Press ENT

Step 4: Drape Forming Process

1. Stamping PETG plastic sheet (grid pattern)
2. Clamping plastic sheet at the thermoforming machine
3. Mold shape placed on vacuum former
4. Heat plastic sheet and seal to the container mold
5. Turn on vacuum and pumps out all the air (through venting line)
6. Wait until plastic sheet cool
7. Switch off vacuum pump
8. Remove plastic sheet from the vacuum part
9. Trim excess plastic

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

All the results obtained discusses in this chapter after conducting the experiment. The results will be expressed in the figures, table, and graph. The results of thermoforming process were explained in detail in this chapter.

4.2 SIMULATION OF MOLD DESIGN

4.2.1 Rectangular Pocket

Simulation of mold had been done by using CATIA V5R21. There are 3 process occurred in one simulation like roughing, Zlevel for semi rough and finishing, and Zlevel for pocketing. Figure 4.1, 4.2, 4.3, 4.4 and 4.5 show the position of tool path, parameter and machining time for part operation of mold.

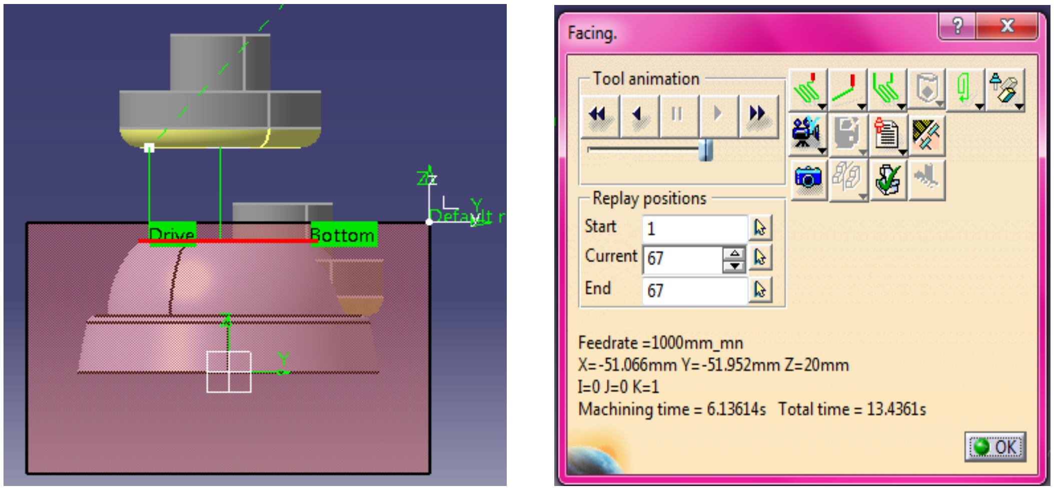


Figure 4.1. Facing Process

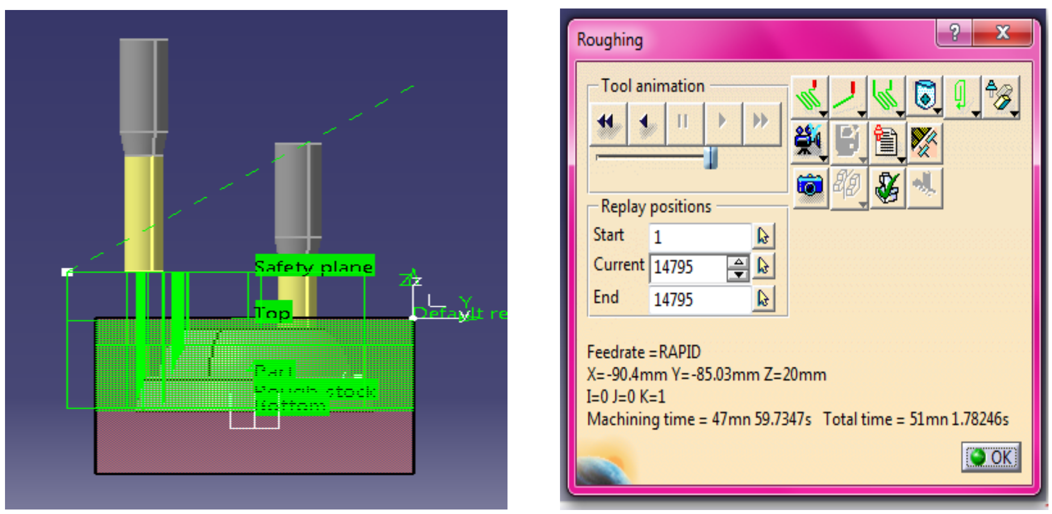


Figure 4.2. Roughing Process

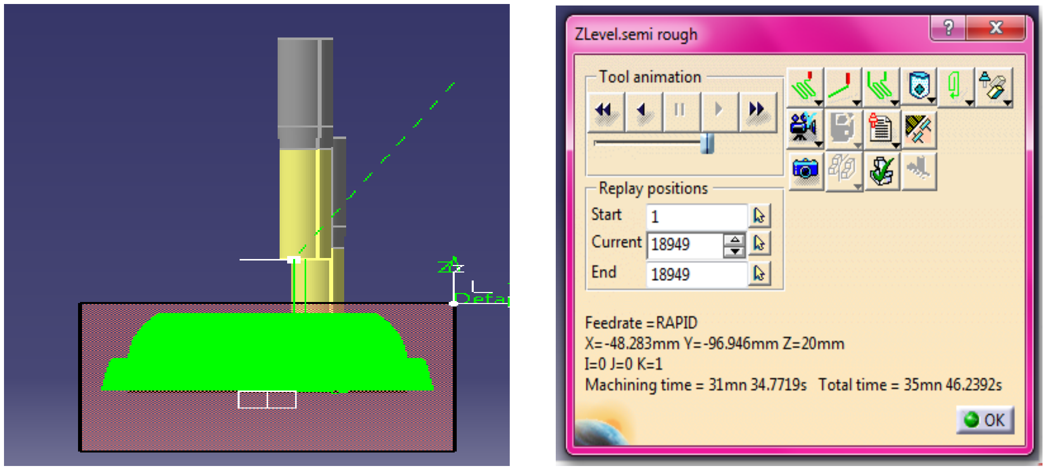


Figure 4.3. Zlevel (semi rough) Process

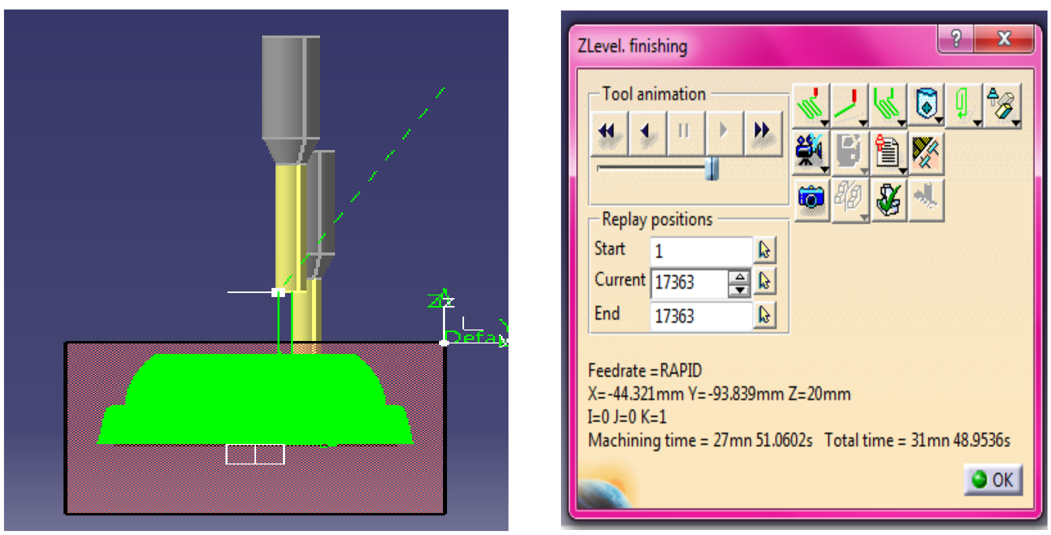


Figure 4.4. Zlevel (finishing) Process

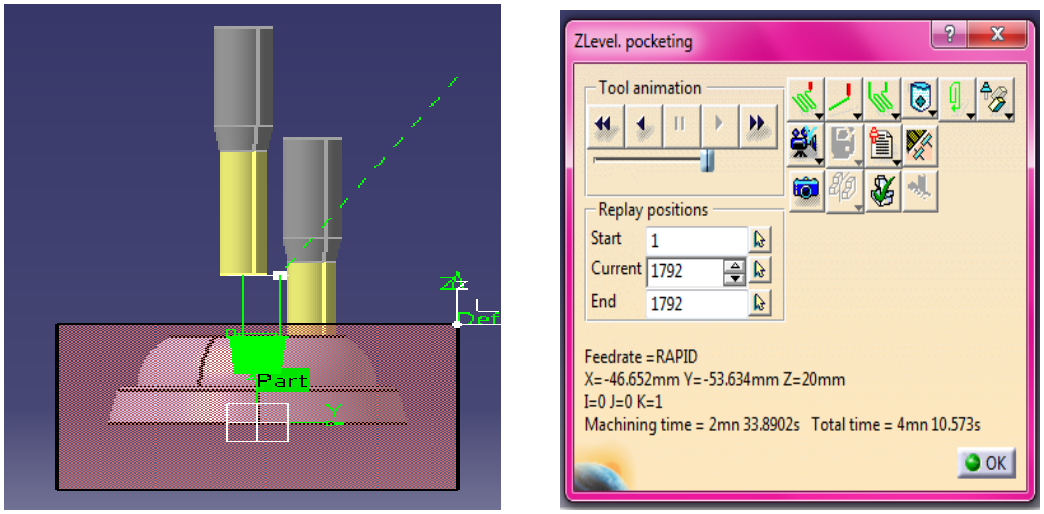


Figure 4.5. Zlevel (pocketing) Process

4.2.2 Circle Pocket

Simulation for Circle pocket is almost similar with the rectangular pocket. But the difference between them only the process of simulation for the pocket (female mold) which circle and rectangular shape. The simulation of tool path, parameter and machining time for circle pocket can refer to Figure 4.1, 4.2, 4.3, and 4.4. Beside that, the simulation process for Zlevel pocketing is difference with rectangular pocket and it shows in Figure 4.6 below.

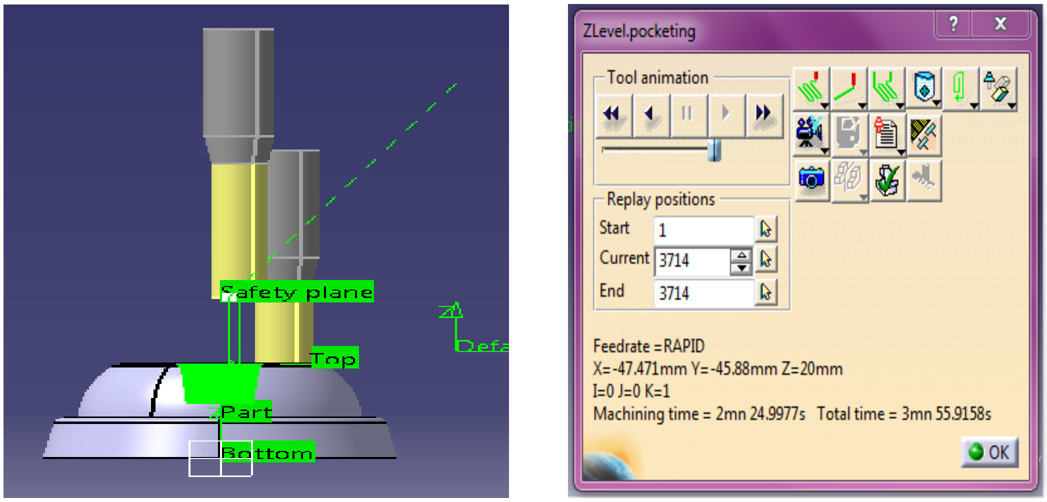


Figure 4.6. Zlevel (pocketing) Process

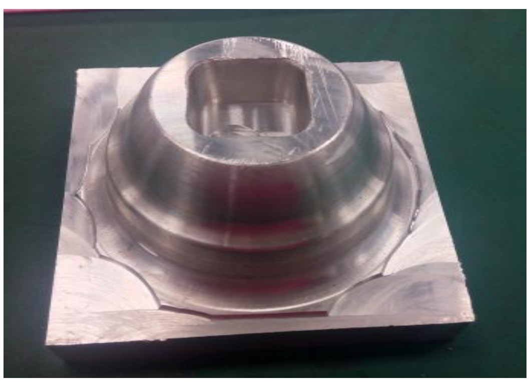
4.3 FABRICATION OF MOLD

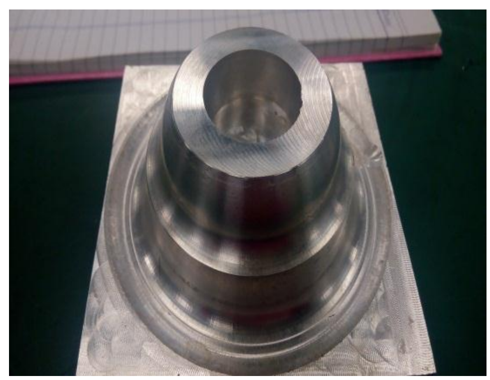
Fabrication of mold had been done by using 3-axis Makino KE55 CNC Milling Machine. All of the NC coding which generated before shown in Appendix B. the standard size for mold was less than 200mm length and 130mm width according to the size of the thermoforming plate mold. Draw ratio = depth of part/width of part. Draw ratio should be less than 2:1 for female mold and 7:1 for male mold.

4.3.1 CNC Milling Machine

Raw material was prepared with aluminum block cut by using band saw for mold. The aluminum blocks squaring by using facing process. The size for both mold (rectangular and circle pocket) was 100mm x 100mm x 50mm.

Figure 4.7. Machining process





Rectangular Pocket

Circle Pocket

Figure 4.8. Finishing Thermoforming Molds

4.3.2 Electric Discharge Machining (EDM) Wire Cut

EDM Wire Cut is a process in which a tool discharges thousands of sparks that are produced between an accurately positioned mowing electrode wire to many types of workpieces like metal, aluminum, and steel. Beside that, high frequency pulses of direct or alternating current is discharged from the wire to the specimen with small spark gap through an insulated dielectric fluid (water).

At one time, there are many sparks can be observed because by discharge sparks lasting in the range of 1/1,000,000 of a second or less, actual discharges can occur more than one hundred thousand times per second. Moreover, desired cutting speed and the surface finish required are depending on the volume of metal removed during this short period of spark discharge.

The estimated heat of each electrical spark at around $15{,}000^{o}$ to $21{,}000^{o}$ Fahrenheit, erodes away a tiny bit of material which is melted and vaporized from the workpiece. These chips (particles) are flushed away from the cut with a stream of de-ionized water through the top and bottom flushing nozzles. The dielectric fluid (water) prevents heat build-up in the workpiece. Thermal expansion of the part would affect positional accuracy and size without this cooling.

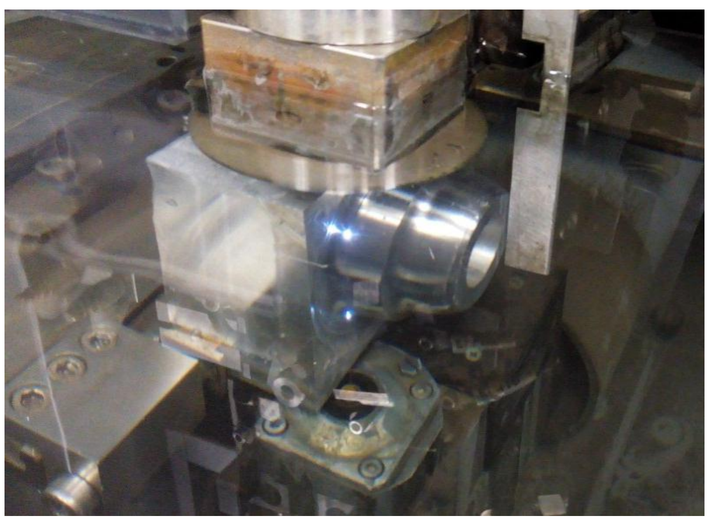


Figure 4.9. Cutting Process

4.4 RESULT OF DRAPE FORMING PROCESS

In this experiment, it proved that venting line plays role important in the thermoforming process. Figure below show the result of the plastic sheet after forming process. Furthermore, we can see that the comparison of plastic sheet between with and without venting line. One of the simplest thermoforming techniques is drape forming process. The plastic sheet is heated and allowed to conform to the shape of the mold under its own weight or with slight mechanical pressure by using either female or male mold. Beside that, the process involves placing the sheet and mold in a hot-air circulating oven. The temperature is raised to the point where the sheet sags between 140^0C to 150^0C and conforms to the shape of the mold. For this experiment, the temperature is constant which is 180^0C.The constant pressure used in this process which is 20 kPa.

The heat time for PETG plastic sheet with thickness 1mm was recommend 50 second in theory, but it will depend on the type of thermoforming machine. For this experiment, the time to reach sagging point is about 2 minutes. The plastic sheet sag at temperature around 70^0C.

Figure 4.10 and 4.11 show the shape of PETG plastic sheet after forming by using difference mold like rectangular and circle pocket of mold which have venting line. Based on the grid, we can see clearly the deformation of plastic toward mold. Moreover, during the drape forming process occurred, the first touched of plastic sheet to the mold had produced the highest thickness, while at the female mold (pocket) was the final touched and it had been the lowest thickness of plastic sheet. Some goes to the circle pocket with has venting line.

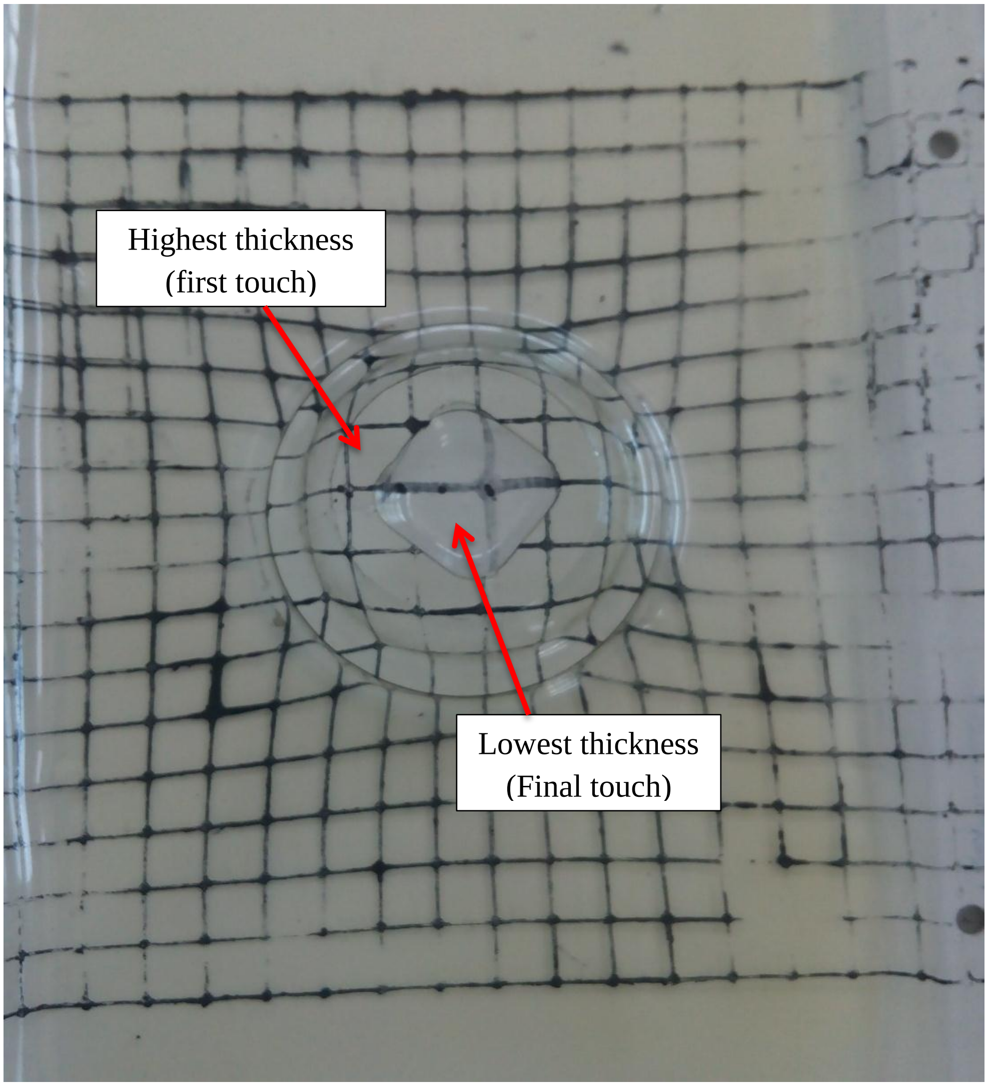


Figure 4.10. Rectangular Pocket (with Venting Line)

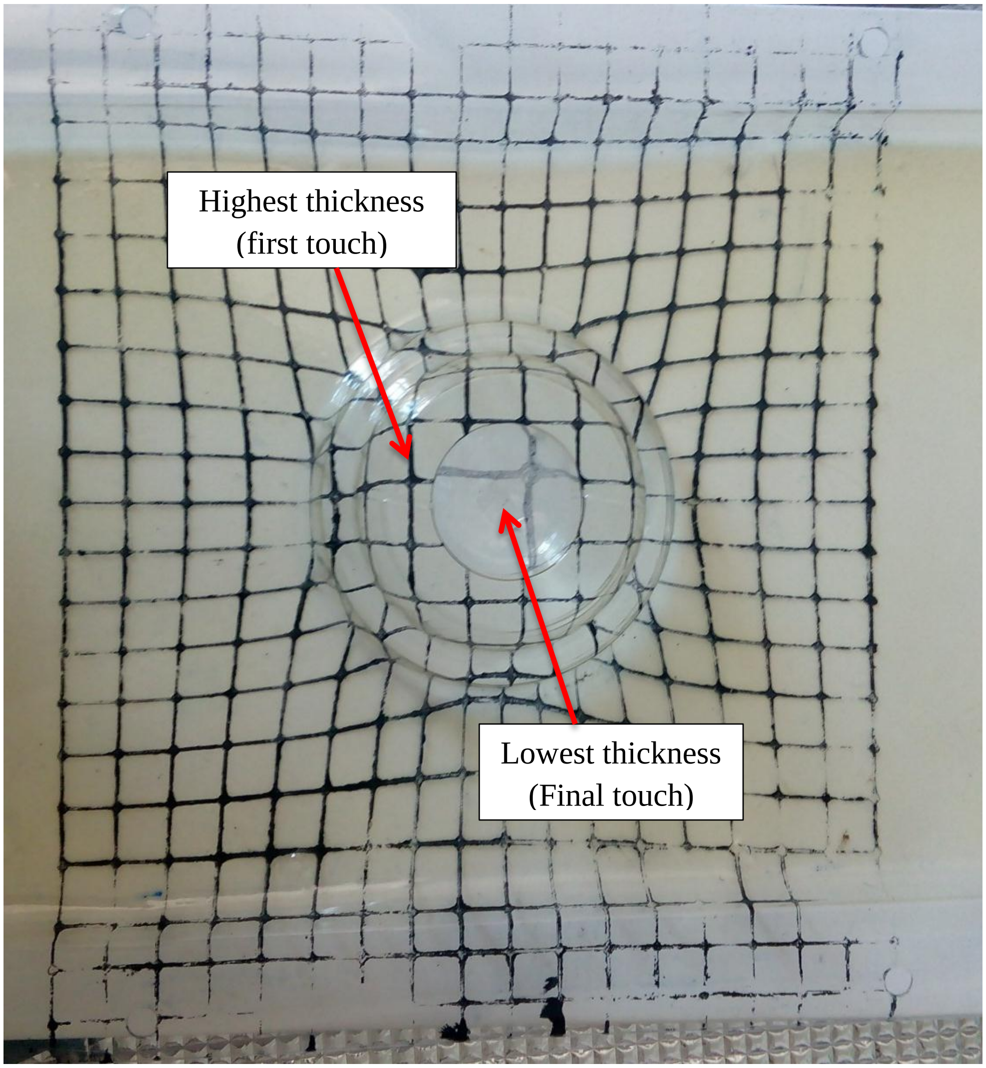


Figure 4.11. Circle Pocket (with Venting Line)

Moreover, Figure 4.12 and 4.13 show the result of drape forming without venting line. By using constant temperature which is 180^0C, the shape of rectangular and circle pocket or can call it as a female mold are not follow the mold shape. This is because there is no air flow during drape forming process that cause the plastic sheet cannot follow the shape of pocket. Then, less deformation occurred to the grid pattern of plastic sheet.

Figure 4.12 shows the deformation of plastic sheet for rectangular pocket of mold which not successfully followed the mold design. The angle of the hemisphere shape should be 90^o. In addition to that, the female mold which was rectangular pocket also not successfully formed because of no venting line created to the mold. Beside that, we can see the deformation of plastic sheet at the base of mold or at the bottom of mold, which was not stretched and formed smoothly.

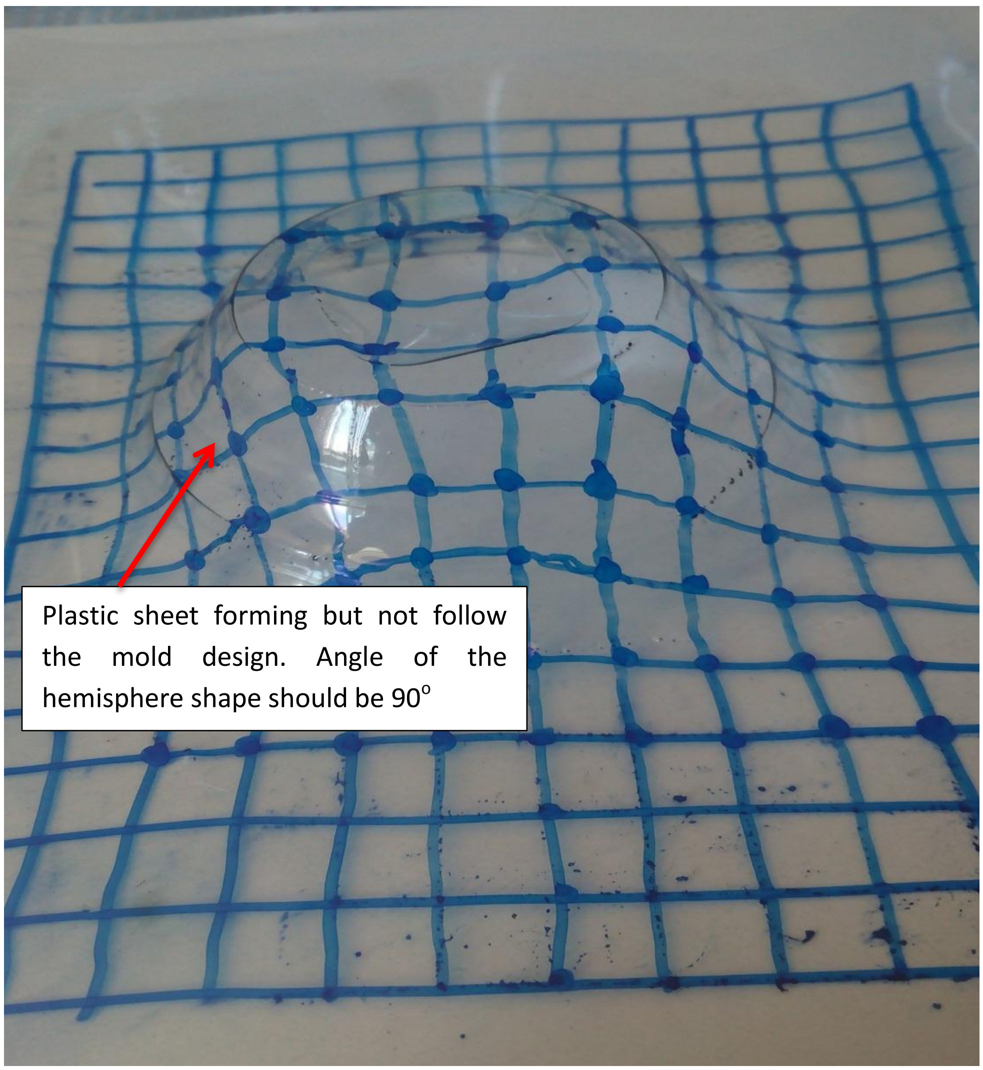


Figure 4.12. Rectangular Pocket (without Venting Line)

Furthermore, for the circle pocket of mold, the shape around the mold was successfully formed, but at the area of circle pocket, it was not followed the mold design. It was just formed a curve. Around the male mold (hemisphere), the plastic sheet was successfully formed because it had formed follow the mold design which was angle 90^o.

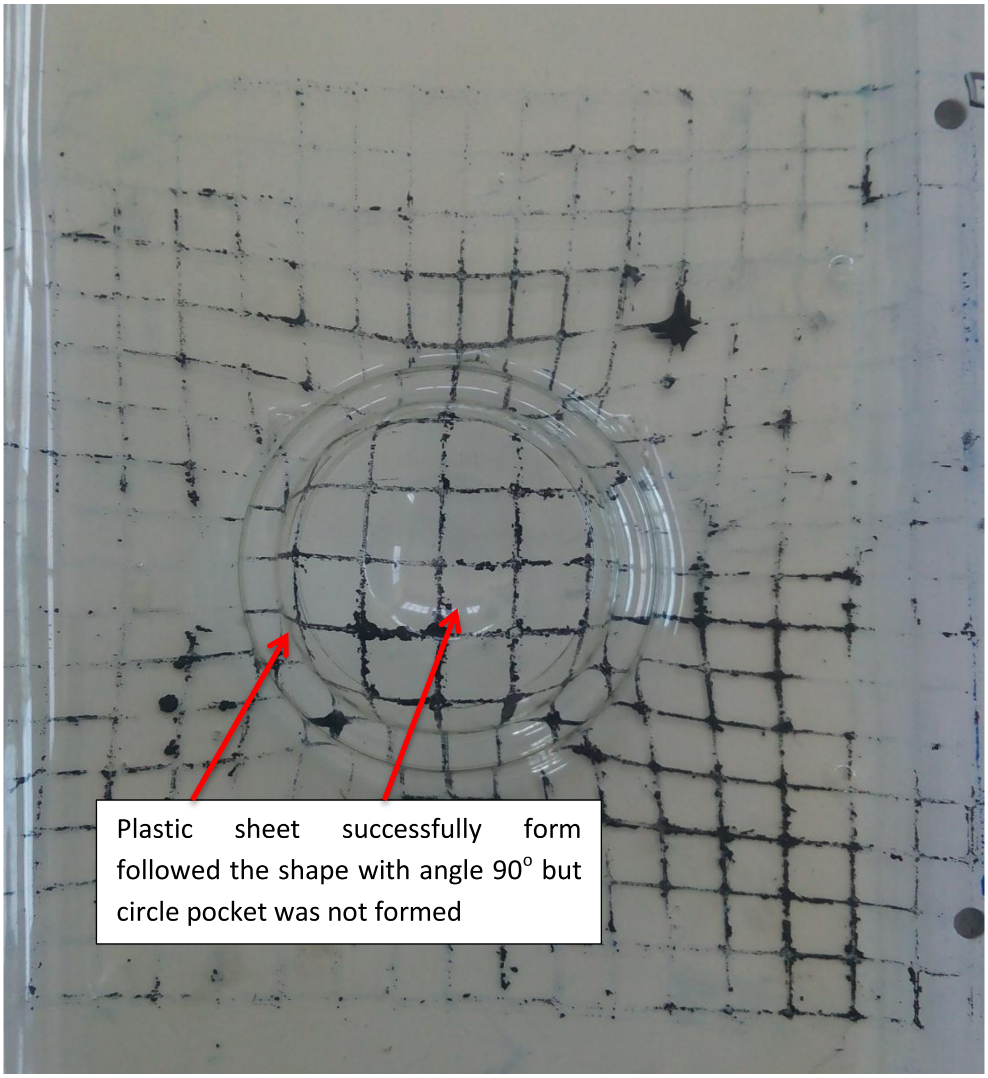


Figure 4.13. Circle Pocket (without Venting Line)

4.5 ANALYSIS THICKNESS OF PETG PLASTIC SHEET

In drape forming process, plastic sheet was strectched over a male mold by raising or lowering the plastic sheet into the mold. The first area of plastic sheet that touch to the mold during forming process will cold earlier than others area and it will ceases to stretch that cause the thickest wall of plastic sheet. Moreover, the final part of sidewall plastic were thinner than the top and the rim has the thinnest wall. Air pressure or vacuum was used to give force to plastic sheet toward mold.

PETG plastic sheet had been analyse by using Microsoft Excel 2010. All of the data were collected by using Micrometer. The actual area between grid pattern was 10mm x 10mm. Figure 4.14 clearly show that the differences between high and low stretch mark area that occured to the plastic sheet. Beside that, the elongation of the grid pattern had been shown that the upper of the plastic part (the area which first touched during vacuum process) has no deformation, thus, retaining the original thickness of plastic sheet which is 1mm. Moreover, when the area of grid pattern is higher, then the thickness of plastic sheet is lower.

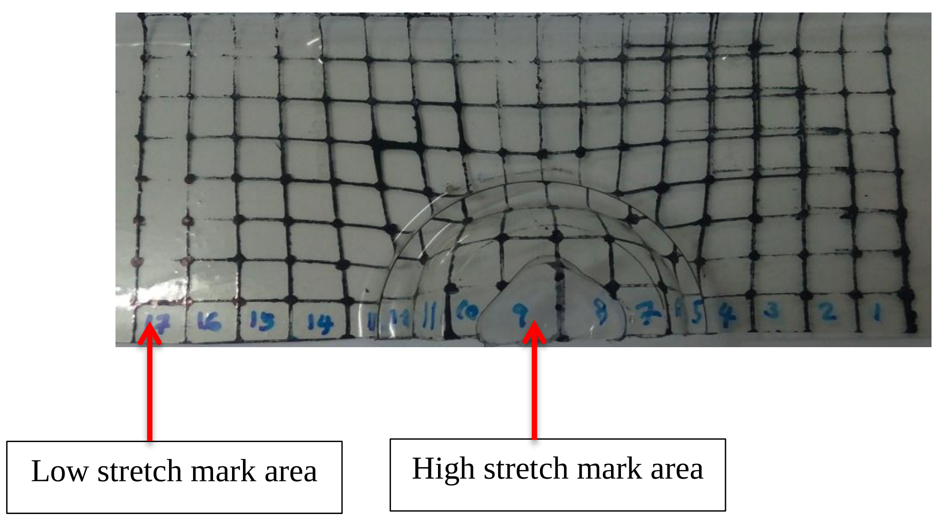


Figure 4.14. Stretch mark area of plastic sheet

The collected data from the rectangular pocket with venting line were shown in Figure 4.15(a). The percentage of thickness versus percentage of plastic stretch had been created. From the graph below, we can see that when the percentage of thickness is higher which is 93% which means that only 7% deformation of plastic occurred during drape forming process. While the percentage of plastic stretch is lower to 11% as in grid number 17 shows. The lower thickness of plastic was occurred at the grid number 8 because the percentage of plastic stretch was reached 20% and the percentage of thickness was become 2% means the thickness of plastic had been lost 98%. Furthermore, the wall plastic sheet of grid number 8 was became the thinner area because the area was last part touched by plastic sheet during drape forming process.

Moreover, at the area of grid number 7 and 10 (for rectangular and circle pocket of mold) were quite similar for both percentages or we can call it as the thickest area because both of the area were tha first area which part touched. In addition to that, the deformation of plastic sheet were less.

The thermoforming of circle pocket (Figure 4.16 (a)) of mold almost same with the rectangular pocket because the percentage of plastic stretch and the percentage of the thickness almost same. This is because of the venting line that applied to the thermoforming mold. For the circle pocket of mold, the lowest percentage of thickness was occurred at line grid number 9 which is 21% (lost 79% thickness of plastic sheet) and the percentage of the plastic stretch become 10% (90% elongation occurred).

Based on Figure 4.15(b) and Figure 4.16 (b) show that the deformation of plastic sheet only occurred in range -1 to 1. The radius of the mold base is 37.5mm (R_{base}). Figure (a) and (b) show the same data but for the graph in figure (b) show about 90% deformation of plastic sheet occurred around the mold, while more 1 or less than -1, only 10% of deformation occurred.

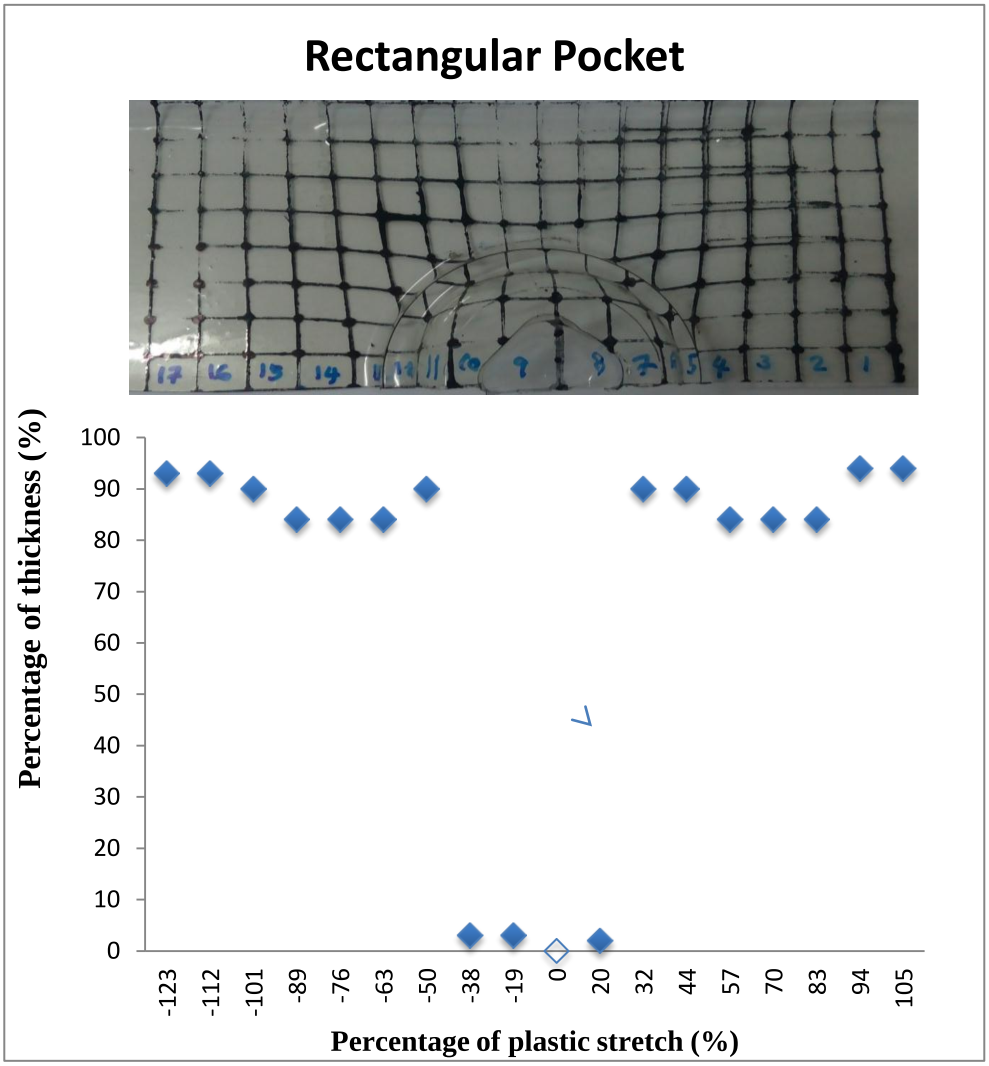


Figure 4.15(a): Percentage of thickness vs. plastic stretch for Rectangular pocket (with venting line)

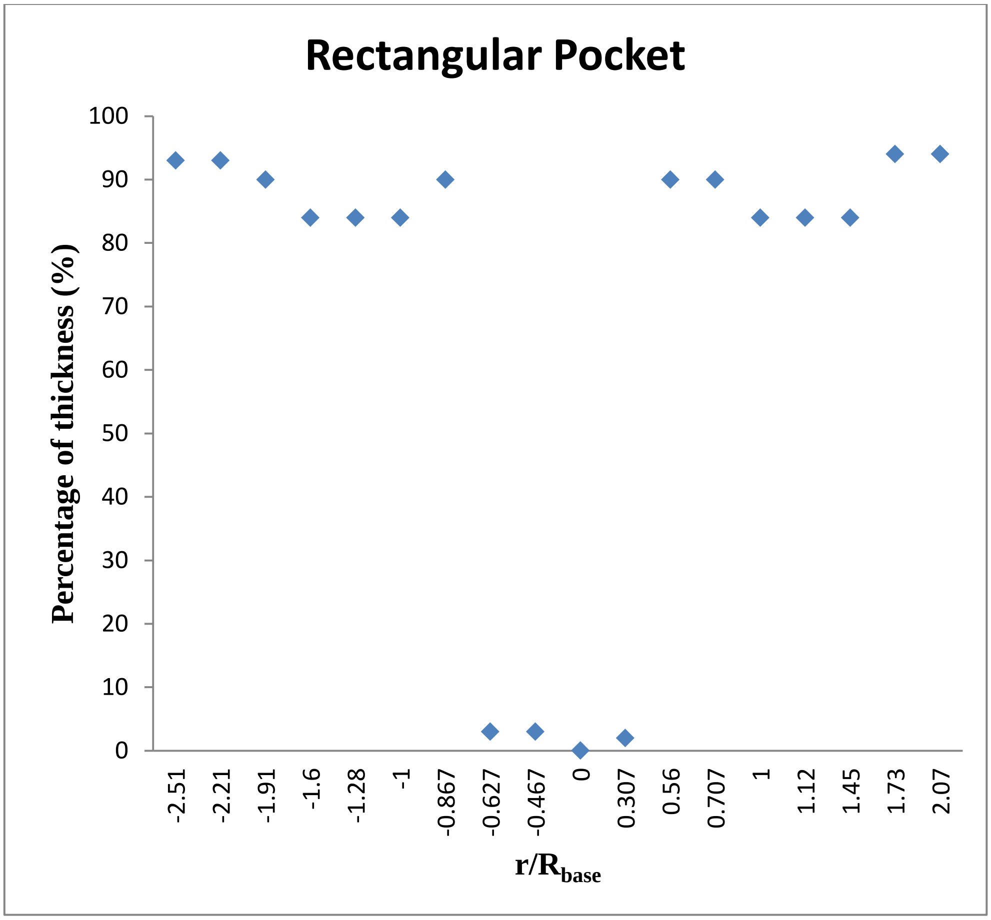
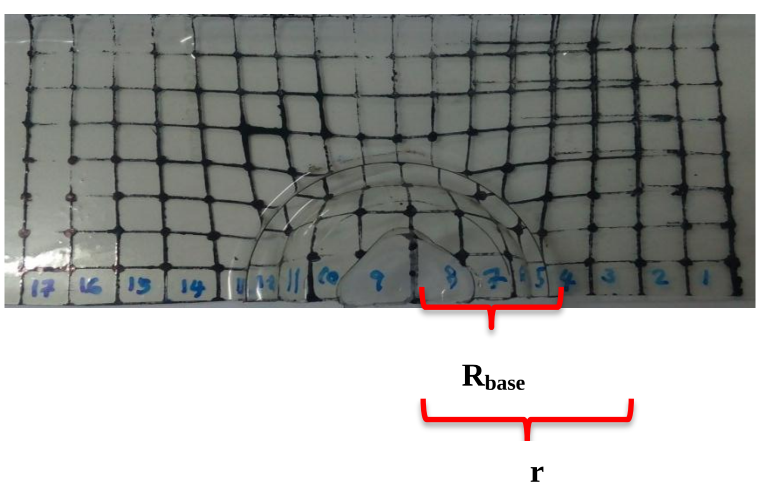


Figure 4.15(b): Percentage of thickness vs. r/R_{base} for Rectangular pocket



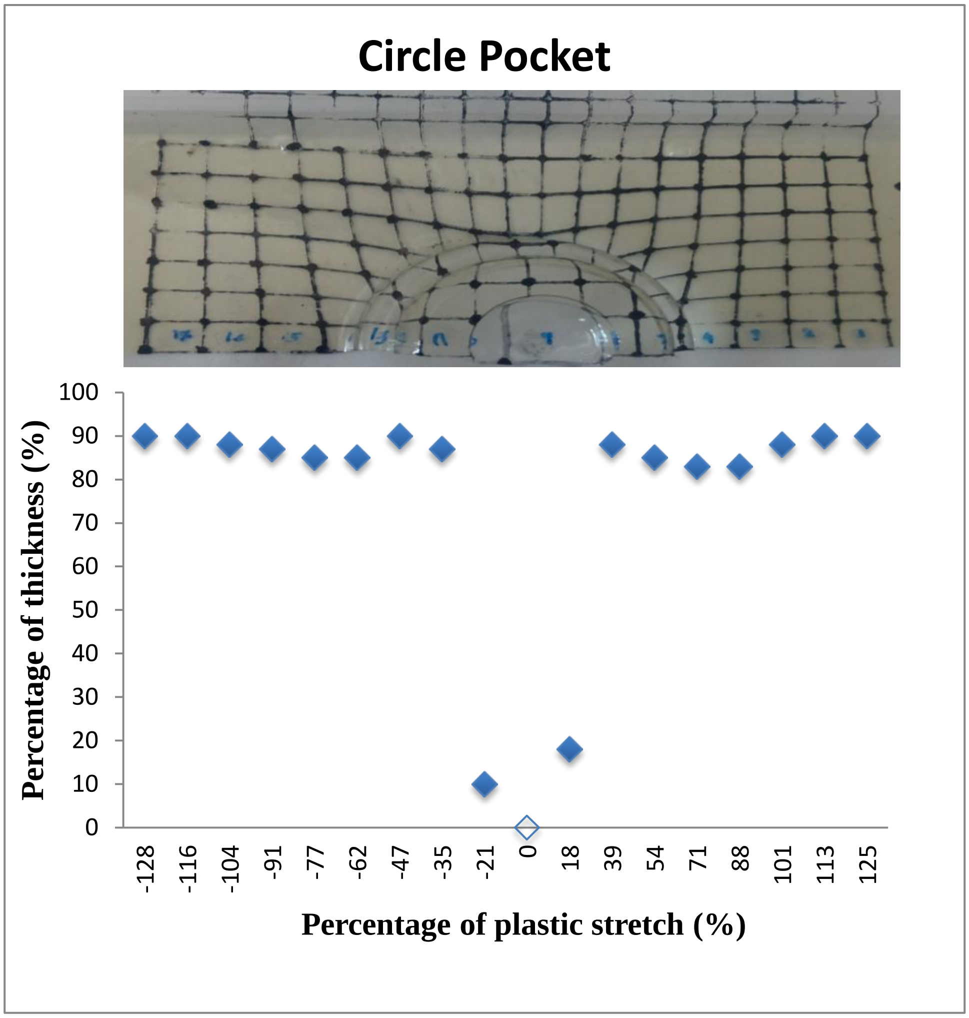


Figure 4.16 (a): Percentage of thickness vs. plastic stretch for Circle pocket (with venting line)

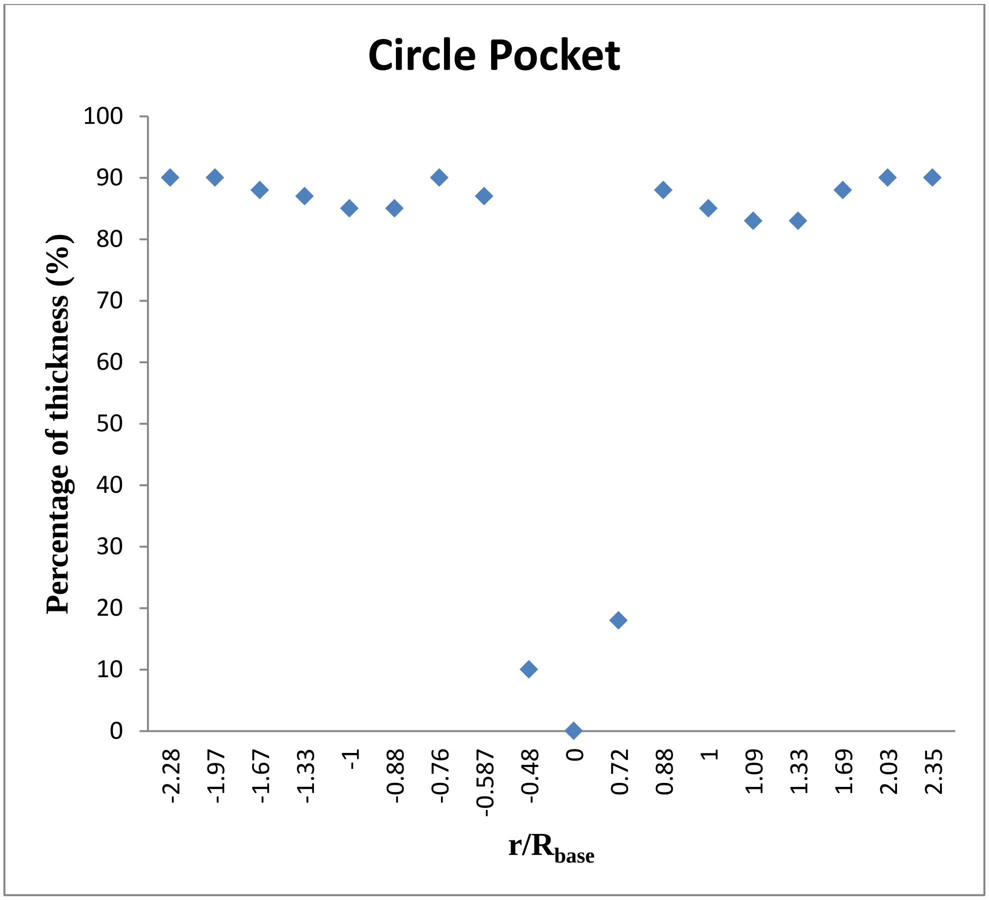


Figure 4.16 (b): Percentage of thickness vs. r/R_{base} for Circle pocket (with venting line)

Figure 4.17(a) and 4.18(a) show the percentage of stretch and thickness for mold which not has venting line. We can see the differences the shape of PETG plastic sheet after forming between mold that has venting line and without venting line. When there is no venting line created to the mold, it means that, there is no space for air to reduce the air trap. Beside that, slightly clogged or incorrect placement venting line result in trapped air pockets that will cause the different amount of stretching in different areas. (Florian, 1998)

From the data collected, the thickness of plastic sheet which mold do not has venting line were less stretch because there were air trapped between mold and plastic sheet. With the conventional angle of female mold, the forming material will stop fully or shortly corner detail. Even with the most ideal mold temperature and heat conditions, the limitation of forming radius will be occurring. The corner or radius of thinner plastic sheet material tend to form is better than heavier-gauged materials. One of the satisfactory methods for all practical purpose by using the plastic sheet material thickness for judging the minimum obtainable radius. Furthermore, the least formable radius in thermoforming, the thickness of the thermoplastic sheet should be used. (Florian, 1998)

Based on the graph below, we can see that the lowest percentage thickness for both plastic sheet (rectangular and circle pocket) around 70% (only lost 30% of thickness), while for the percentage of plastic stretch was only 14% elongate. Beside that, at the pocket area of mold, the PETG plastic sheet were not successfully followed the shape of the mold. It was because there was no venting line created to mold. From graph 4.17, for the highest percentage of thickness was reached 100% because there was no deformation occurred to the plastic sheet.

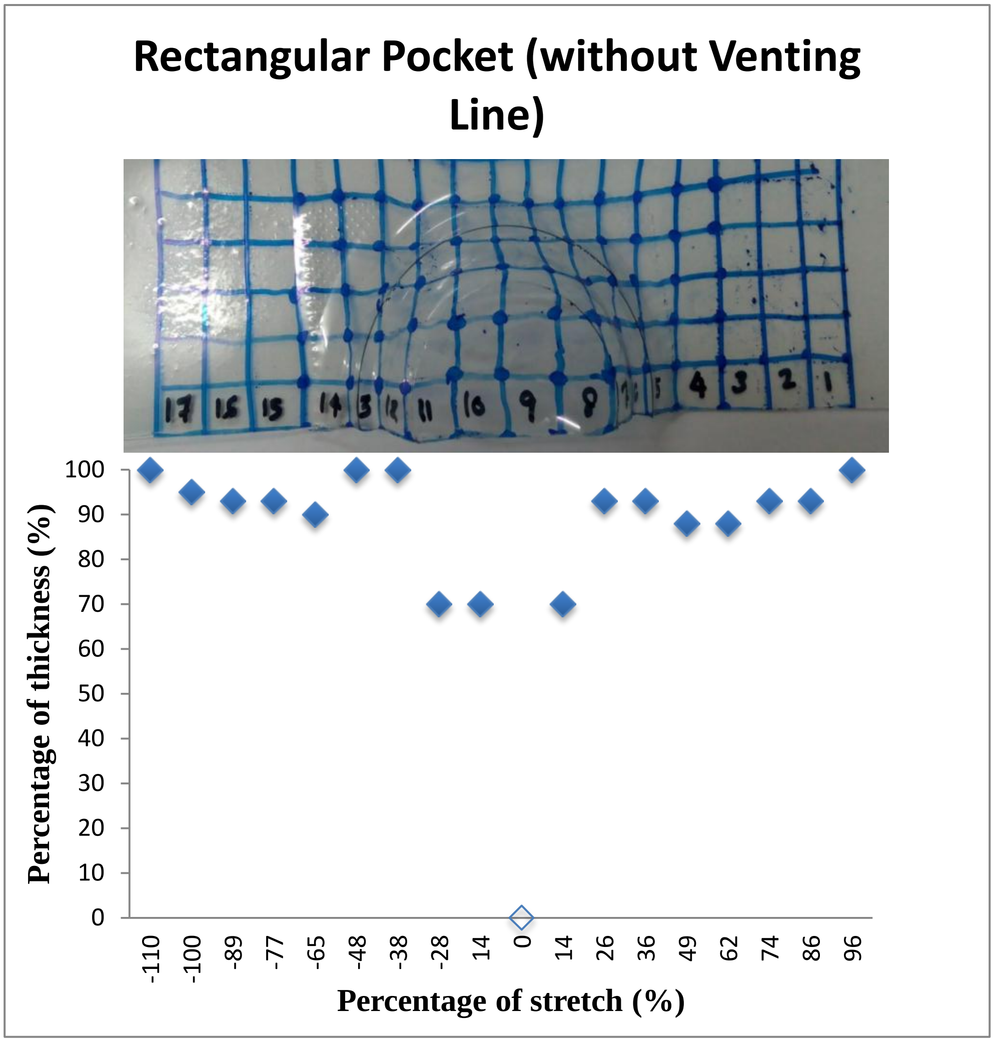


Figure 4.17 (a) : Percentage of thickness vs. plastic stretch for Rectangular pocket (without venting line)

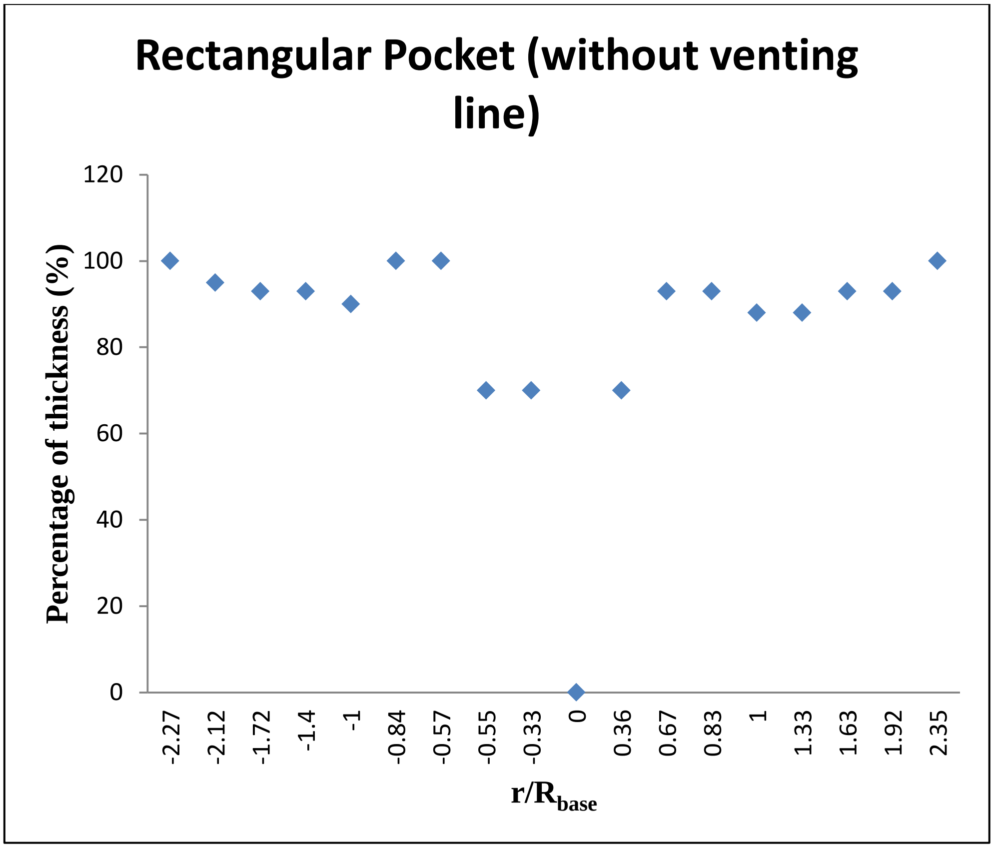


Figure 4.17 (b): Percentage of thickness vs. r/R_{base} for Rectangular pocket (without venting line)

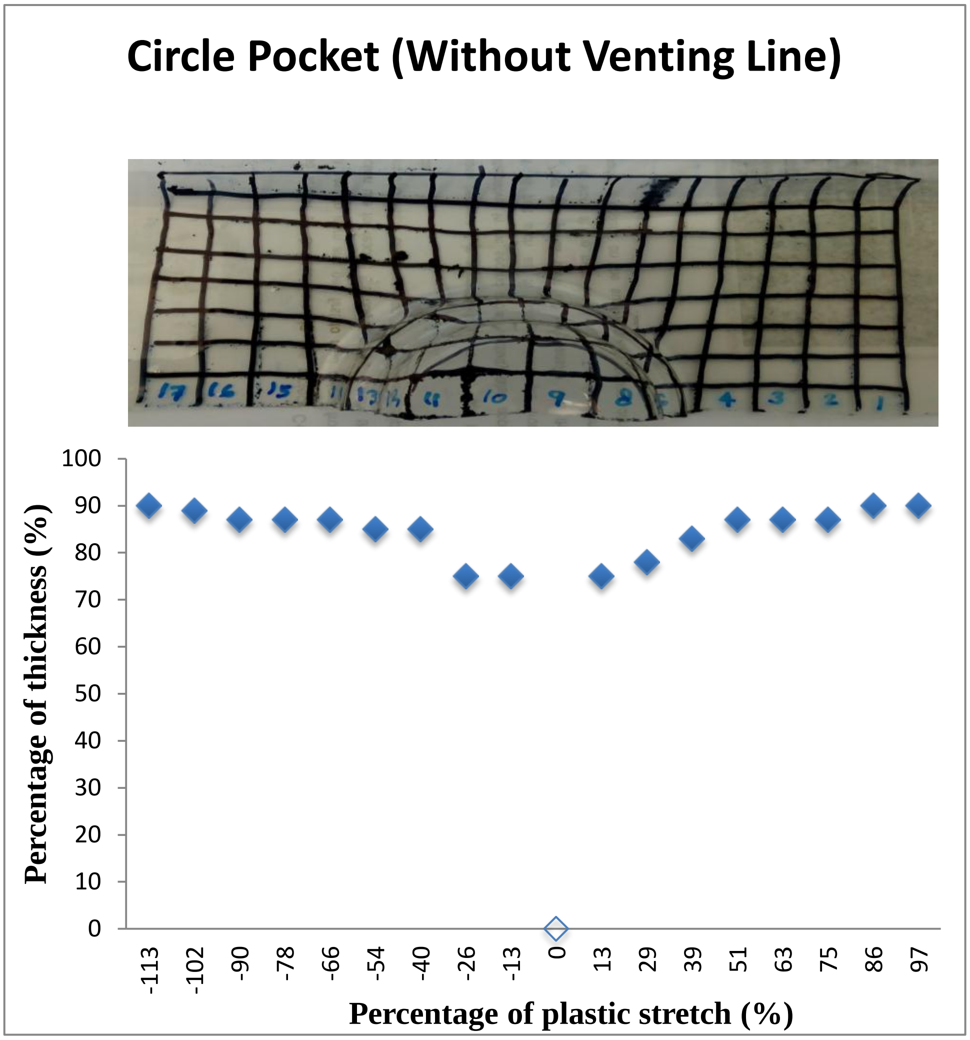


Figure 4.18 (a): Percentage of thickness vs. plastic stretch for Circle pocket (without venting line)

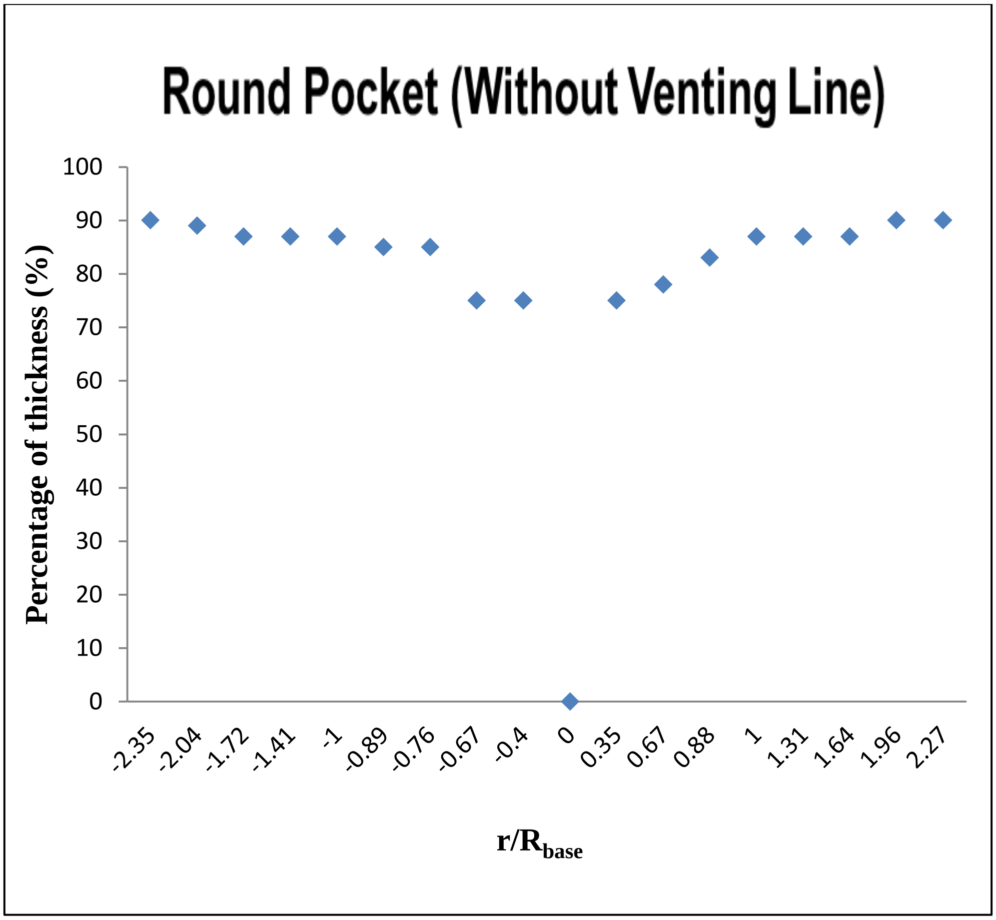


Figure 4.18(b): Percentage of thickness vs. r/R_{base} for Circle pocket (without venting line)

4.6 DISCUSSIONS

Based on the result above, 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 nowadays. Drape forming process is a technique using a single positive mold, on which a heated plastic sheet is placed. After the plastic sheet is softened by thermal processing, it sags and conforms to the shape of the mold under its own weight or by slight pressure applied by an operator.

This experiment had been conducted by starting with design part and mold for the thermoforming. Mold design had been successfully fabricated by using CNC Milling Machine and EDM Wire Cut. The process of fabricating the mold had been explained in the methodology in Chapter 3 before. After that, venting line was created for both different pocket or female of molds which were rectangular and circle pocket. Here, I would like to highlight that, venting line plays role important in the thermoforming process because it help the drape forming process for producing the plastic sheet which follow the mold design. Therefore, we no need to use plug to form the shape of female mold or pocket of mold because venting line acts as an air flow by reducing the air.

Moreover, the experiment had been conducted by using different type of female mold which were rectangular and circle pocket which tested by using different ways like mold with venting line and mold without venting line. As we can see form result before, the plastic sheet with mold that has venting line were formed successfully follow the shape of mold. But, plastic sheet with mold that without venting line were not truly followed the shape of mold especially female mold (pocket). After drape forming process occurred, we can see the first touched of plastic sheet was produced the highest thickness, while the final touched of plastic sheet has lower thickness. Therefore, the percentage of thickness versus percentage of plastic stretch was recorded and showed in the graph above.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The interpretation and summary of the study in several sections will conclude in this chapter. From the first chapter gives a concise overview of the study, including method of the experiment and finding in relation to the research questions and hypothesis.

5.2 CONCLUSIONS

There are numerous types of application and patterns that specify the range of conditions for successful capsule and thermoforming production. Moreover, specifications or features of mold shapes, temperature and pressure ranges, venting line placements and vacuum conditions can be found in the prior art.

Based on the discussion, we can conclude that, venting line plays role important in thermoforming process. Beside that, it is very suitable for the mold which have module in the same mold like female and male mold. Based on the experiment, I had reviewed the engineering design process for PETG plastic part which is thermoplastic sheet used in engineering applications. Furthermore, thermoforming process had been designed by using constant temperature of plastic sheet like 180^0C for heating process. Moreover, we no need use to the common method that used in industry like plug or venting hole to assist the female mold forming because venting line was created to the mold. Then, PETG plastic part was produced successfully by using drape forming process which applying all of the features that created to the mold like draft angle, fillet and venting line.

Last but not least, the thermoforming process had been successfully producing great useful products. Moreover, the industry that used thermoforming method has not only replaced existing products but they had been created new products.

5.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the result obtained from the previous chapter, there are a few recommendations for future research such as:

1) The parameter of thermoforming mold like spindle speed and feed rate should be carefully selected in order to reduce all kinds of defect that will occur to mold surface.
2) Make sure the features of mold design will follow the guideline of designing the thermoforming mold like draft angle, fillet, and venting line or venting hole
3) During the thermoforming process, do not heat the PETG plastic sheet to more than 193^o. Overheat plastic sheet will cause defect like webbing and changing color of plastic sheet (become yellow).
4) From the heat of thermoforming, to remove plastic sheet emissions, always provide adequate ventilation.
5) First surface decorations should be used for male mold, and for the second surface application for female mold.
6) Always keep in mind the depth of draw should be kept in a minimum because the steeper the draft, the thinner the plastic sheet.

7) Before begin the thermoforming process, making a test to confirm that the PETG plastic sheet will performs satisfactorily for the intended application and the equipment.

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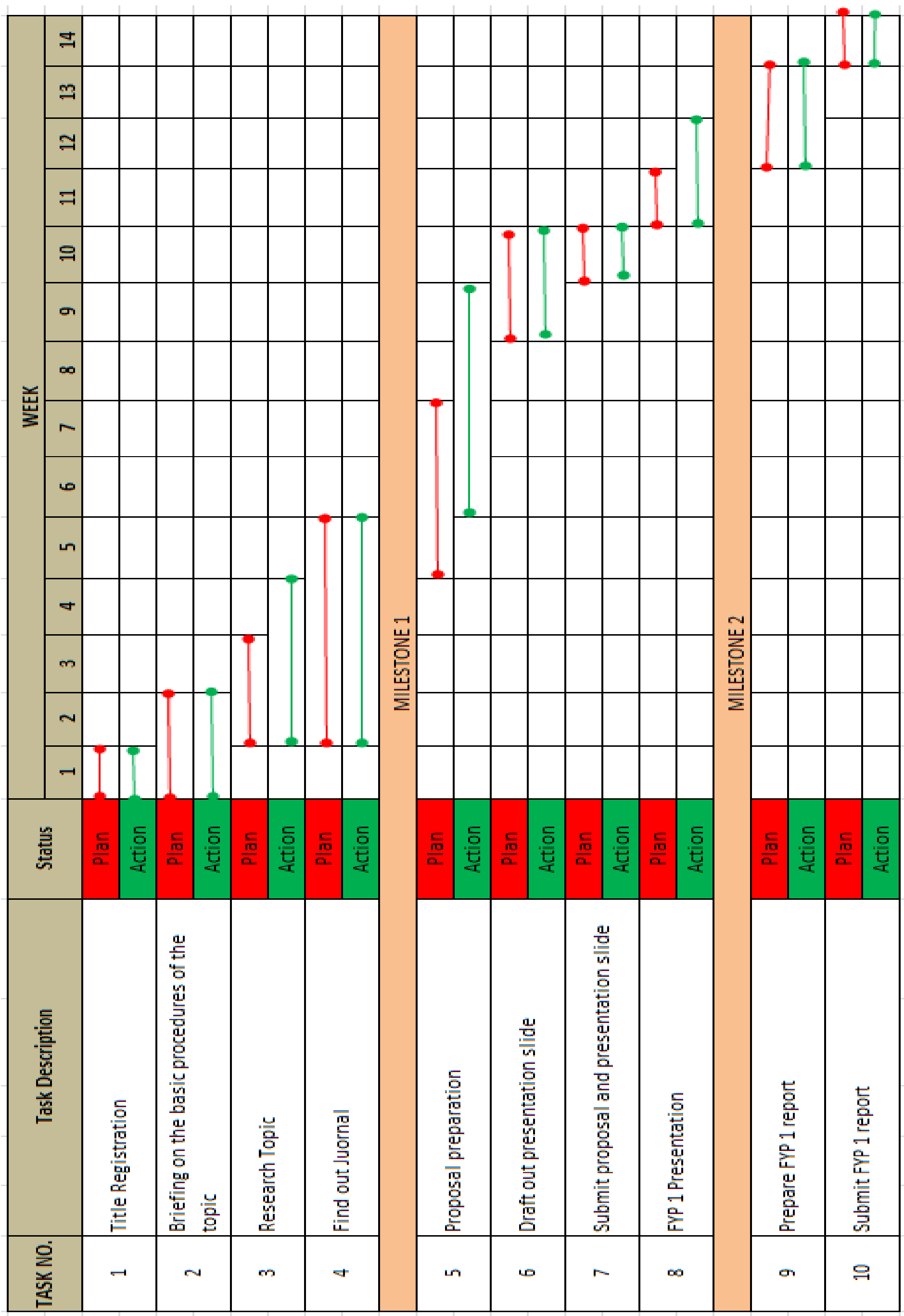
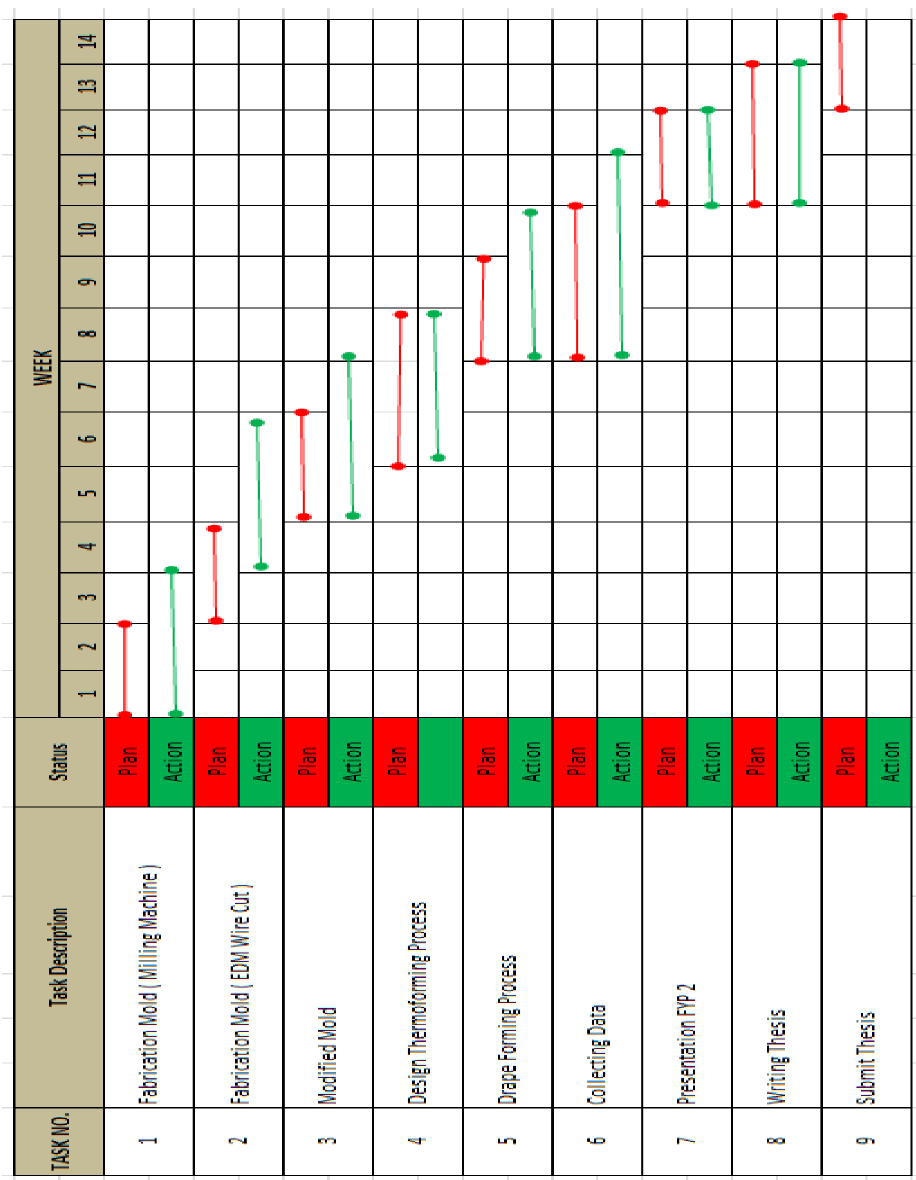
APPENDIX A

GANTT CHART

A.1 Gantt Chart FYP 1



A.2 Gantt Chart FYP 2



APPENDIX B

TABLE OF RESULTS

Table 4.1: Data of Rectangular Pocket (with venting line)

Grid No.	Rectangular Pocket		
	Percentage of plastic stretch (%)	Percentage of thickness (%)	$\frac{r}{R}$
17	-123	93	-2.51
16	-112	93	-2.21
15	-101	90	-1.91
14	-89	84	-1.6
13	-76	84	-1.28
12	-63	84	-1
11	-50	90	-0.867
10	-38	3	-0.627
9	-19	3	-0.467
	0	0	0
8	20	2	0.307
7	32	90	0.56
6	44	90	0.707
5	57	84	1
4	70	84	1.12
3	83	84	1.45
2	94	94	1.73
1	105	94	2.07

Table 4.2: Data of Circle Pocket (with venting line)

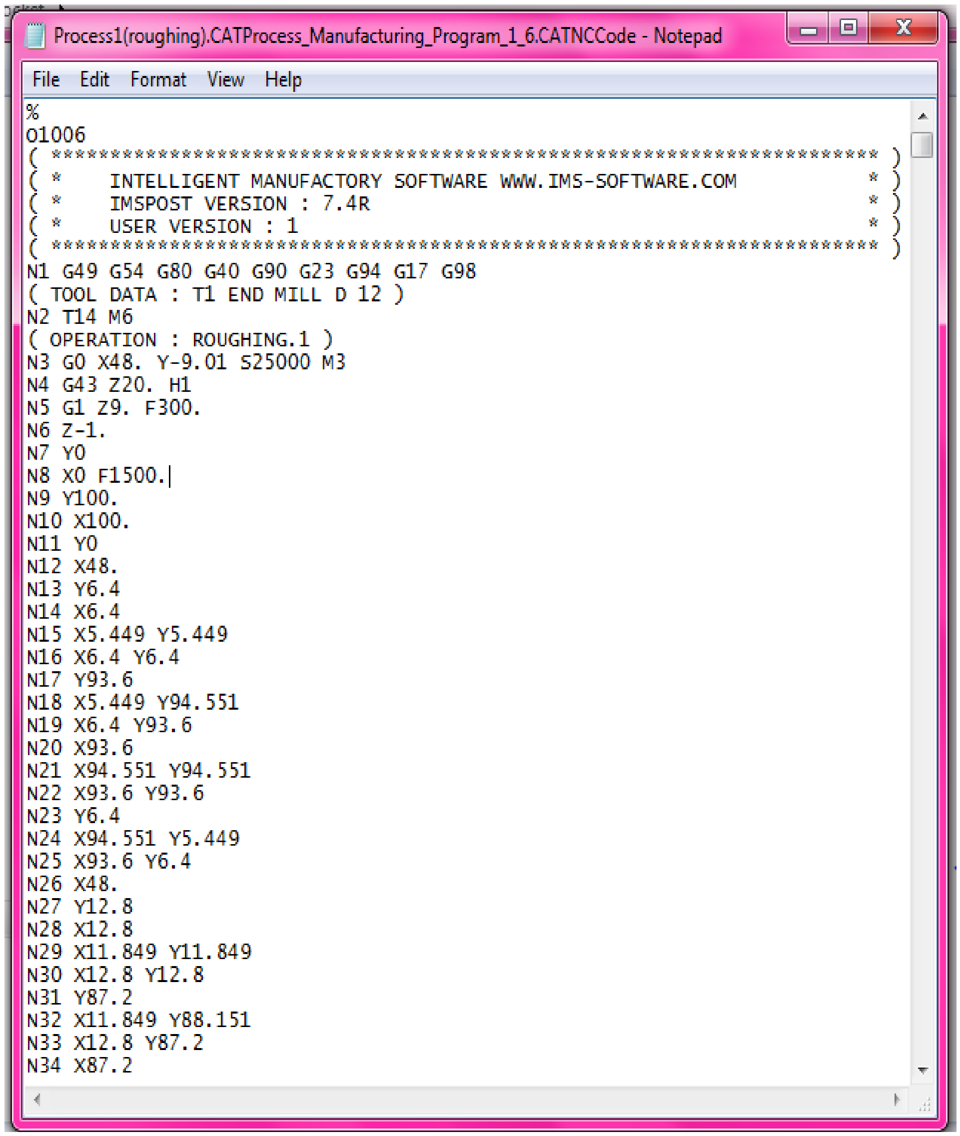
Grid No.	Rectangular Pocket		
	Percentage of plastic stretch (%)	**Percentage of thickness (%)**	$\frac{r}{R}$
17	-128	90	-2.28
16	-116	90	-1.97
15	-104	88	-1.67
14	-91	87	-1.33
13	-77	85	-1
12	-62	85	-0.88
11	-47	90	-0.76
10	-35	87	-0.587
9	-21	10	-0.48
	0	0	0
8	18	18	0.72
7	39	88	0.88
6	54	85	1
5	71	83	1.09
4	88	83	1.33
3	101	88	1.69
2	113	90	2.03
1	125	90	2.35

Table 4.4: Data of Circle Pocket (without venting line)

Grid No.	Circle Pocket		
	Percentage of plastic stretch (%)	**Percentage of thickness (%)**	$\frac{r}{R}$
17	-113	90	-2.35
16	-102	89	-2.04
15	-90	87	-1.72
14	-78	87	-1.41
13	-66	87	-1
12	-54	85	-0.89
11	-40	85	-0.76
10	-26	75	-0.67
9	13	`75	-0.4
	0	0	0
8	13	75	0.35
7	29	78	0.67
6	39	83	0.88
5	51	87	1
4	63	87	1.31
3	75	87	1.64
2	86	90	1.96
1	97	90	2.27

Table 4.3: Data of Rectangular Pocket (without venting line)

Grid No.	Rectangular Pocket		
	Percentage of plastic stretch (%)	**Percentage of thickness (%)**	$\frac{r}{R}$
17	-110	100	-2.27
16	-100	95	-2.12
15	-89	93	-1.72
14	-77	93	-1.4
13	-65	90	-1
12	-48	100	-0.84
11	-38	100	-0.57
10	-27	70	-0.55
9	12	70	-0.33
	0	0	0
8	12	70	0.36
7	24	93	0.67
6	36	93	0.83
5	49	88	1
4	62	88	1.33
3	74	93	1.63
2	86	93	1.92
1	96	100	2.35



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N18 X5.449 Y94.551
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N20 X93.6
N21 X94.551 Y94.551
N22 X93.6 Y93.6
N23 Y6.4
N24 X94.551 Y5.449
N25 X93.6 Y6.4
N26 X48.
N27 Y12.8
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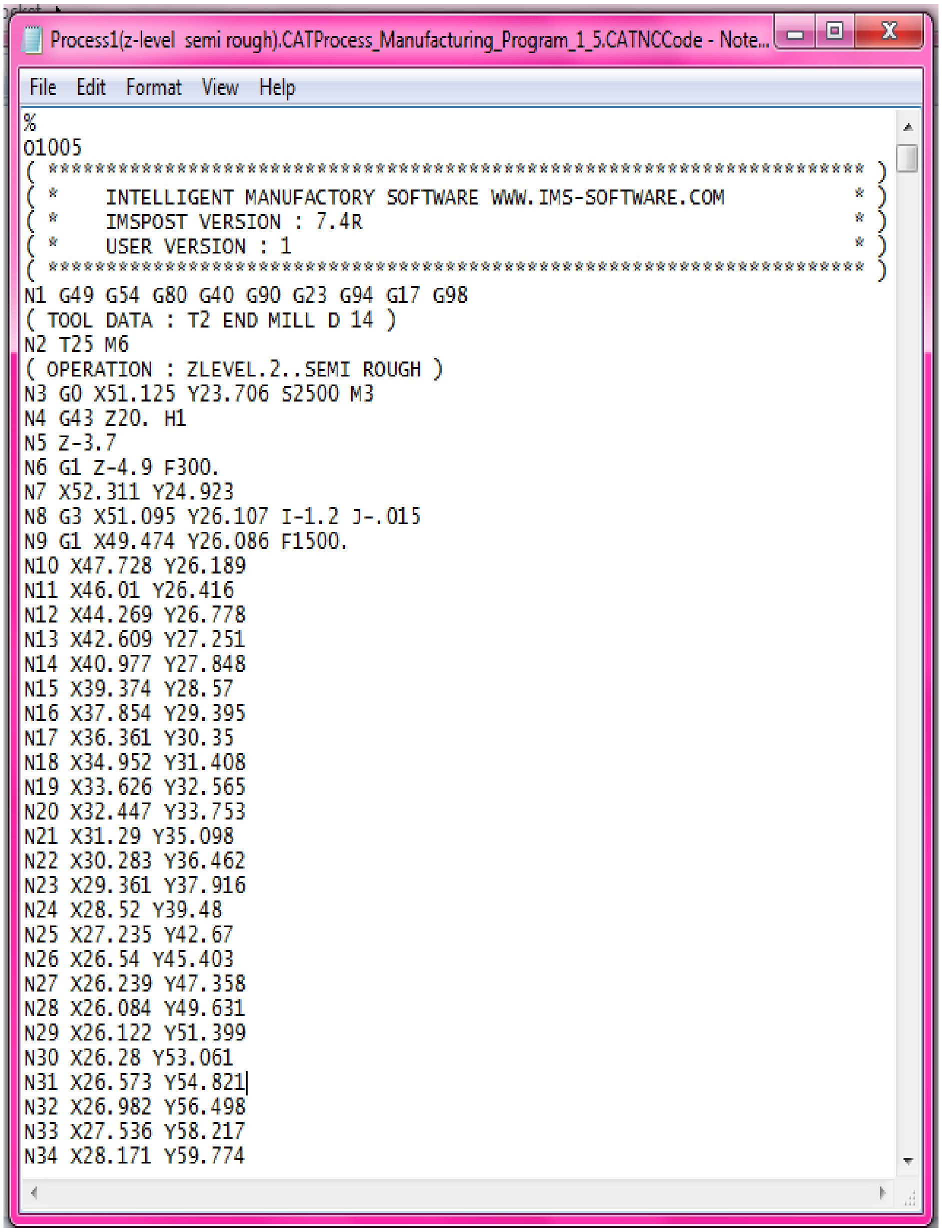
Figure 4.19. NC Coding for Roughing Process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N4 G43 Z20. H1
N5 Z-3.7
N6 G1 Z-4.9 F300.
N7 X52.311 Y24.923
N8 G3 X51.095 Y26.107 I-1.2 J-.015
N9 G1 X49.474 Y26.086 F1500.
N10 X47.728 Y26.189
N11 X46.01 Y26.416
N12 X44.269 Y26.778
N13 X42.609 Y27.251
N14 X40.977 Y27.848
N15 X39.374 Y28.57
N16 X37.854 Y29.395
N17 X36.361 Y30.35
N18 X34.952 Y31.408
N19 X33.626 Y32.565
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N21 X31.29 Y35.098
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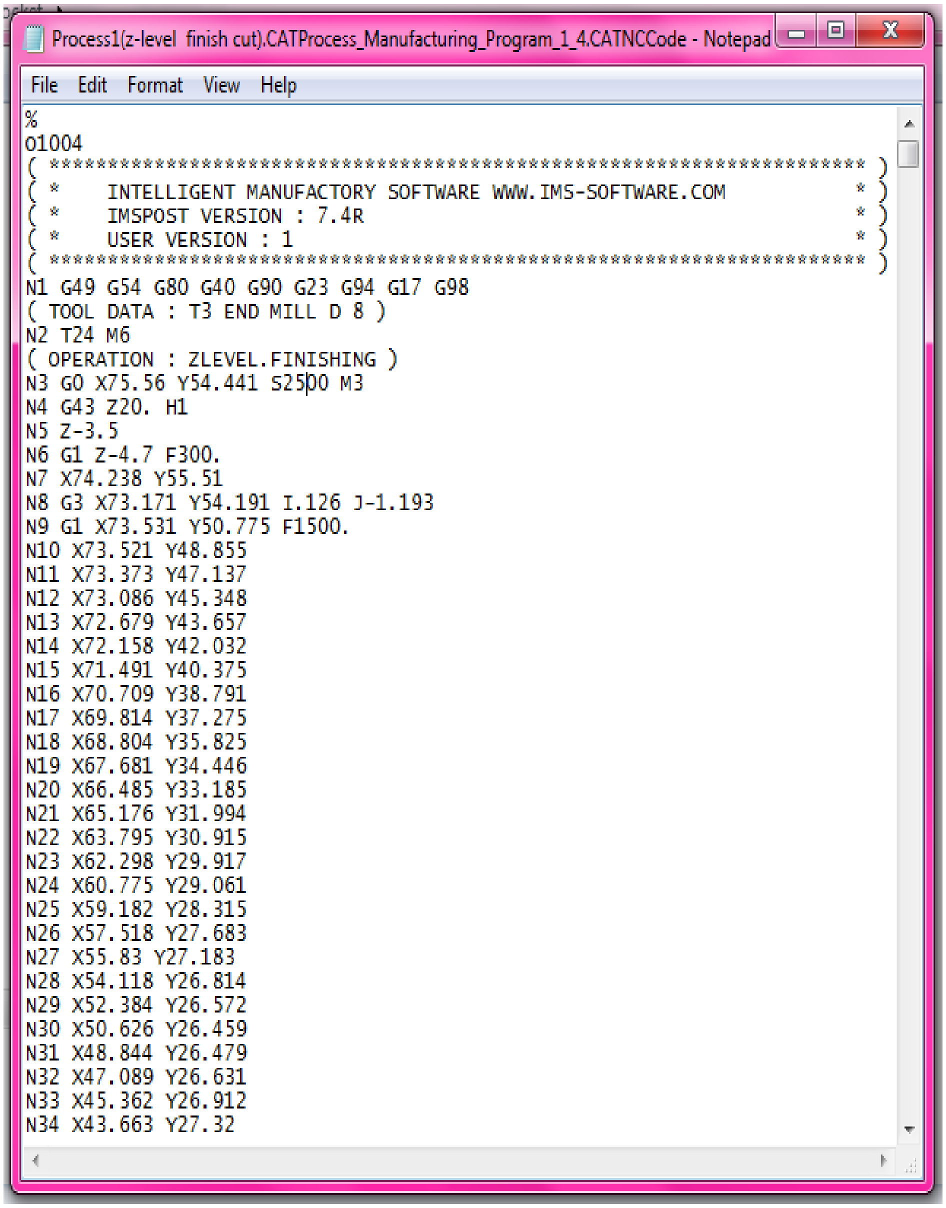
Figure 4.20. NC Coding for Zlevel (semi rough) Process

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N4 G43 Z20. H1
N5 Z-3.5
N6 G1 Z-4.7 F300.
N7 X74.238 Y55.51
N8 G3 X73.171 Y54.191 I.126 J-1.193
N9 G1 X73.531 Y50.775 F1500.
N10 X73.521 Y48.855
N11 X73.373 Y47.137
N12 X73.086 Y45.348
N13 X72.679 Y43.657
N14 X72.158 Y42.032
N15 X71.491 Y40.375
N16 X70.709 Y38.791
N17 X69.814 Y37.275
N18 X68.804 Y35.825
N19 X67.681 Y34.446
N20 X66.485 Y33.185
N21 X65.176 Y31.994
N22 X63.795 Y30.915
N23 X62.298 Y29.917
N24 X60.775 Y29.061
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N27 X55.83 Y27.183
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N29 X52.384 Y26.572
N30 X50.626 Y26.459
N31 X48.844 Y26.479
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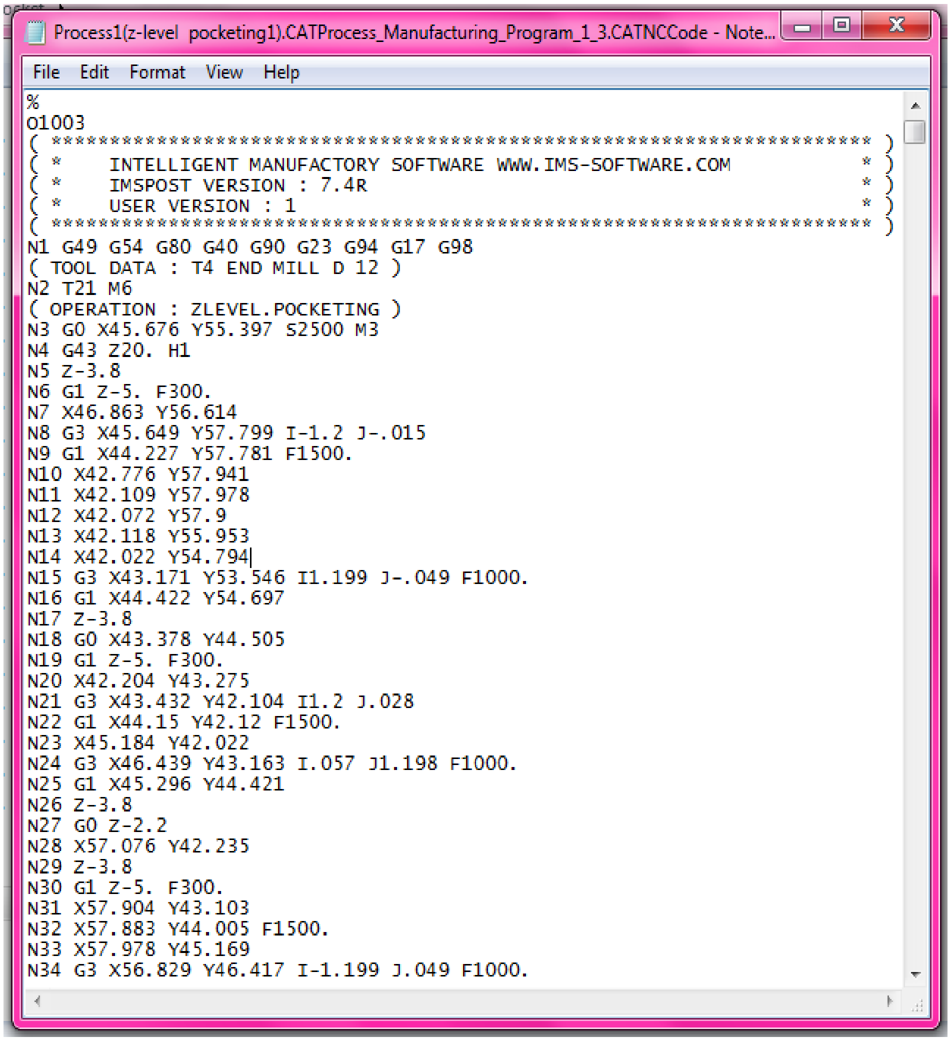
Figure 4.21. NC Coding for Zlevel (finishing) Process



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( OPERATION : ZLEVEL.POCKETING )
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N7 X46.863 Y56.614
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N9 G1 X44.227 Y57.781 F1500.
N10 X42.776 Y57.941
N11 X42.109 Y57.978
N12 X42.072 Y57.9
N13 X42.118 Y55.953
N14 X42.022 Y54.794
N15 G3 X43.171 Y53.546 I1.199 J-.049 F1000.
N16 G1 X44.422 Y54.697
N17 Z-3.8
N18 G0 X43.378 Y44.505
N19 G1 Z-5. F300.
N20 X42.204 Y43.275
N21 G3 X43.432 Y42.104 I1.2 J.028
N22 G1 X44.15 Y42.12 F1500.
N23 X45.184 Y42.022
N24 G3 X46.439 Y43.163 I.057 J1.198 F1000.
N25 G1 X45.296 Y44.421
N26 Z-3.8
N27 G0 Z-2.2
N28 X57.076 Y42.235
N29 Z-3.8
N30 G1 Z-5. F300.
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N32 X57.883 Y44.005 F1500.
N33 X57.978 Y45.169
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Figure 4.22. NC Coding for Zlevel (pocketing) Process

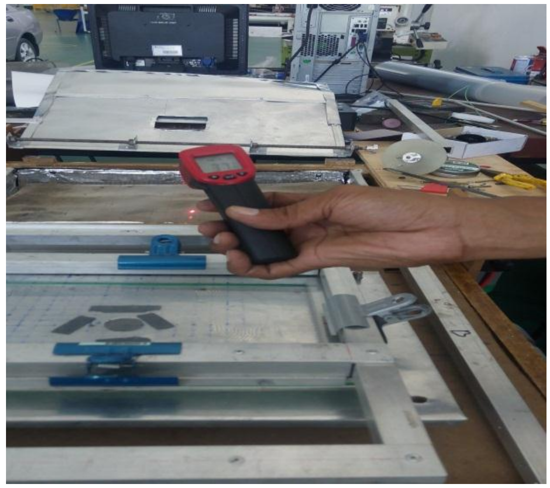
APPENDIX C

MACHINE AND EQUIPMENT USED IN EXPERIMENT

C.1 Horizontal Band Saw Machine

C.2 Cutting Material process by Using Horizontal Bans Saw Machine

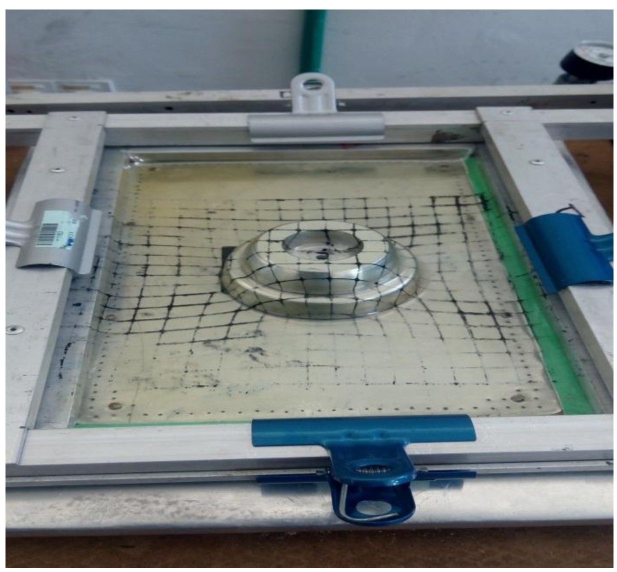
C3 Testing temperature of Plastic sheet after drape forming process by using Laser Infrared Temperature Gun



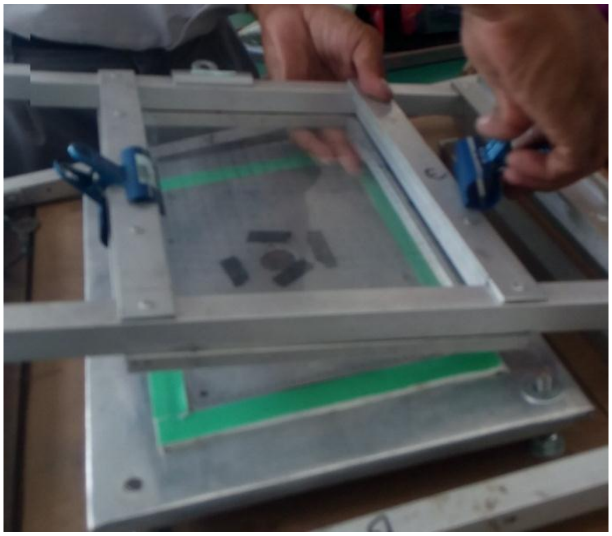
C4 Stamping Plastic Sheet Process

C5 The PETG plastic sheet sagging at temperature 150^0

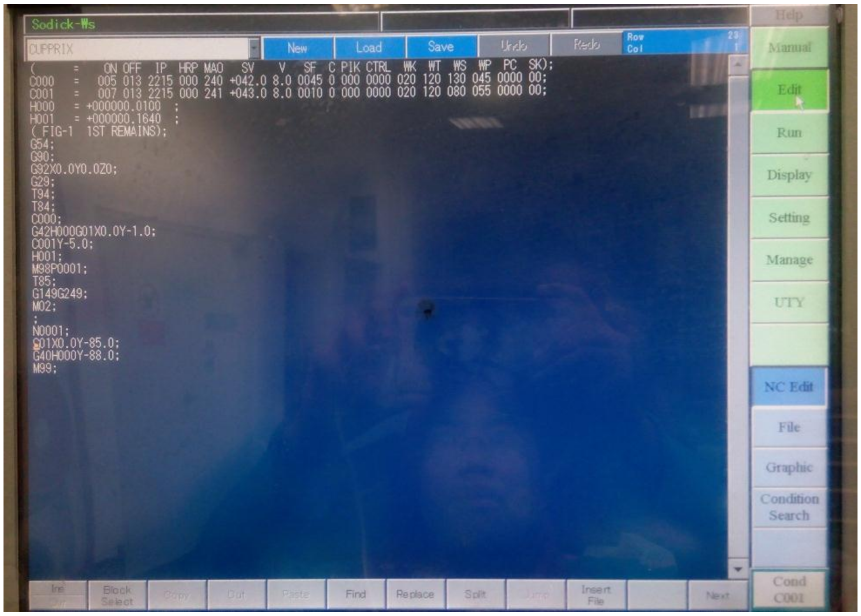
C6 Cooling process



C7 Clamping plastic sheet



C8 NC Coding for EDM Wire Cut



C9 Laser Infrared Temperature.

C10 Mitutoyo Micrometer