DESIGN AND DEVELOPMENT OF VACUUM FORMING MACHINE

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**This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (Design and Innovation)**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MAY 2017

DECLARATION

I declare that this project report entitled "Design and Development of Vaccuum Forming Machine" is the result of my own work except as cited in the references

Signature :

Name : CHIN CHUN YOK

Date : 13/6/2017

APPROVAL

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

Signature

Name of Supervisor : MOHD NIZAM SUDIN

Date : 13/6/17

DEDICATION

To my beloved mother and father

ABSTRACT

Vacuum forming machine is a machine that performs vacuum forming process in which a plastic sheet is heated to suitable temperature, stretched around into a mould and then comformed to the mould by creating vacuum pressure between the plastic sheet and surface of mould. There are many products manufactured by vacuum forming process. They are becoming increasing popular because of the low cost and convenient modification. However, the vacuum forming machine in the marketplace is expensive and large. This would be extremely unwise to buy an expensive vacuum forming machine just for personal use or the small amount of usage. Therefore, in this project, a simple and low cost vacuum forming machine was designed and developed for learning purpose. At first, the dominant requirements were determined, that is low manufacturing and maintenance cost, easy to operate, safe and etcetera. In this project four design concept of vacuum forming machines were designed with the methods such as brainstorming, objective tree, morphological chart and etc. The Pugh method was used to select the best design concept. All designs were evaluated based on product design specifications that are performance, appearance and economy. Finally, Design concept 4 was selected due to its outstanding features compared to others. Then, Design concept 4 was drawn in detail by Software CATIA V5R20. Product analysis were carried out in order to calculate and determine the required amount of power supply to heat the plastic sheet until it is soften. The results have known that 1.5mm thickness of ABS plastic sheet can be soften and formed after being heated at around 44 W in 3 min. After that, a prototype was fabricated and tested. The estimated price for the prototype of vacuum forming machine is about RM 108.89.

ABSTRAK

Vacuum forming merupakan sebuah tehnik sederhana yang menggunakan selembar plastic yang dipanaskan pada temperatur tertentu, dan kemudian diregangkan ke dalam sebuah mould atau cetakan. Vakum membentuk Mesin adalah sebuah mesin yang melaksanakan proses tersebut. Pada masa kini, banyak produk di sekeliling kita adalah dihasilkan oleh proses ini. Mereka menjadi semakin popular kerana kos rendah dan pengubahsuaian mudah. Walau bagaimanapun, vakum membentuk Mesin adalah mahal dan besar di pasaran. Oleh itu, kebanyakkan penguna tidak mampu membeli mesin ini untuk tujuan perobadi. Oleh itu, vakum membentuk Mesin yang mudah dan murah telah direka dan dibangunkan dalam projek ini. Keperluan pelanggan terhadap mesin ini telah ditentukan sebelum mesin direka dan dibentukan. Dalam projek ini, empat jenis mesin telah direka dengan menggunakan kaedah seperti brainstorming, objective tree, carta morfologi dan sebagainya. Kaedah Pugh telah digunakan untuk memilih reka bentuk yang terbaik. Semua rekabentuk telah dinilai berdasarkan spesifikasi produk seperti prestasi, rupa dan ekonomi. Akhirnya, konsep 4 telah dipilih kerana ciri-ciri yang cemerlang berbanding dengan konsep-konsep lain. Kemudian, konsep 4 telah dilukis secara terperinci dengan menggunakan Perisian CATIA V5R20. Analisis produk telah dijalankan untuk mengira dan menentukan jumlah bekalan kuasa yang diperlukan untuk memanaskan lembaran plastik sehingga ia melembutkan. Keputusan menunjukkan bahawa lembaran plastik ABS yang ketebalan 1.5mm boleh dilembutkan dan dibentukkan selepas dipanaskan dengan 44 W selama 3 min. Prototaip telah dibina dan diuji. Harga anggaran prototaip mesin adalah RM 108.89.

ACKNOWLEDGEMENT

Firstly, I would like to express my outmost gratitude to Universiti Teknikal Malaysia Melaka for providing me an opportunity to pursue Projek Sarjana Muda (PSM) or Final Year Project (FYP) as a partial fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering (Design and innovation). Next, I would like to express my deepest appreciations to my project supervisor; Dr Mohd Nizam bin Sudin, for consultants throughout the project. Thank you for always guide me and advise me in producing an excellent report. Besides that, I would like to thank my parents and friends that always motivate me and support me in accomplishing the project. Thank you for trying your best to assist me during prototype development.

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LIST OF ABBEREVATIONS

UTEM	Universiti Teknikal Malaysia Melaka
FKM	Faculty of Mechanical Engineering
ABS	Acrylonitrile butadiene styrene
PVC	Polyvinyl chloride
PS	Polystyrene
PP	Polypropylene
PC	Polycarbonates
FIG	Figure
Eq	Equation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

According to Collins Dictionary, vacuum forming is a process in which a heated thermoplastic sheet is shaped by pressing it toward a mould and applying suction.Vacuum forming machine is a machine that performs vacuum forming process in which a plastic sheet is heated to suitable temperature, stretched around into a mould and then comformed or fit to the mould by creating vacuum pressure between the plastic sheet and surface of mould.

There are few steps and process involved in vacuum forming process. First, a mould is made and put on the platens of the vacuum forming machine. Then, a thermoplastic sheet is clamped in place and placed above the mould. The heater, which is positioned above the plastic, will heat up to warm the plastic. Then, the mould is moved up to the hot flexible and mouldable plastic sheet. The vacuum is switched on and all the air which is under the plastic will be expelled out, allowing the plastic to form the shape of the mould. Finally, the sheet is moved from its mould and excess parts are cut and trimmed.

Nowadays, many products around us are manufactured by vacuum forming process. They are becoming increasing popular because of the low cost and convenient modification. The most common products that made from vacuum forming include open plastic containers, food packaging, sink units, and others. The vacuum forming process has many advantages over blow moulding, injection moulding and other plastic forming processes. However, it is too expensive and large; it is unwise to buy it just for the small amount of usage. Therefore, in this project, a low cost, small size vacuum forming machine will be designed and analyzed for educational purpose.

According to Plasticpedia, vacuum forming is "comparatively low cost tooling" it requires less sophisticated tools and relatively inexpensive materials to produce the mould. Large parts can be produced from one sheet of plastic to save the quantity cost. Besides that, small runs can be prototyped economically compared to other processes. Furthermore, vacuum forming is also a time efficient plastic forming process. Engineer don't need to spend many time on the designing the product because the vacuum forming process is a simple manufacturing process. Nowadays, vacuum forming has become technically controlled through the simulation process with the necessary expertise. Therefore, vacuum forming is a great potential for development of processing methods in the plastic processing field.

1.2 PROBLEM STATEMENT

The existing vacuum forming machine in the marketplace is expensive and large. This would be extremely unwise to buy an expensive vacuum forming machine just for personal use with the small amount of usage. Therefore, a simple and low cost vacuum forming machine will be designed and developed for learning purpose.

1.3 OBJECTIVE

The objective of this research project is to design and develop a simple and low cost vacuum forming machine which can produce many different products from thermoplastic effectively.

1.4 SCOPE OF PROJECT

The scopes of this project are:

This project will focus primarily on the design and development of the vacuum forming machine. A simple and low cost vacuum forming machine will be designed and drawn with the aid of CATIA software. Engineering design method and tools such as the morphological chart, Decision Matrix, and others may be applied in designing the vacuum forming machine. Finally, a simple and low cost prototype will be built up as a teaching aid in university.

Project Limits/Boundaries/Work Elements:

The vacuum forming machine will be designed for manual operation. The type of plastic material will be used is ABS plastic. ABS is a thermoforming plastic that can easily be vacuum-formed or shaped by heating and bending. It is thin enough that it can be cut with scissors or a utility knife. In this project, the temperature of heating will be fixed to around 150 degree Celsius; this is based on the formability of selected materials. Besides that, this project will not cover simulation of air flow inside the vacuum forming machine. Due to the limitation of budget, the size and materials used in prototype development will not identical to the proposed solution. Therefore, the result of product testing may be different due to the difference in materials.

1.5 GENERAL METHODOLOGY

In order to achieve the objectives of the project, there are few tasks that need to be carried out, those actions are listed as below.

i. Identify Problem

The existing problem will be identified by conducting the literature review to many reading sources such as journals, research papers, articles and other relevant reading materials.

ii. Customers' Requirements

A market analysis will be carried out to identify and clarify the customer's needs. After that, all the customers' requirements will be organized in an objective tree for a better view. Then, a functional analysis will be conducted to know the main function and sub-functions of the product. Finally, and product design specification will be set according to market analysis results and objective tree.

iii. Conceptual Design

Brainstorming will be used to generate a large quantity of alternative for each function of the proposed solution. All the proposed solutions will be evaluated by Decision Matrix in order to select the best solution.

iv. Detail Design

After the best conceptual design is chosen, the researcher will design their product in more detail way which includes types of materials used for the product, manufacturing cost, manufacturing process and the geometric dimension of the product. Lastly, the product will be drawn by using CATIA V5R20.

v. Product Analysis

Once the product is well defined, a complete analysis is conducted. In the analysis process, the integrity of the design in terms of its safety, material, manufacturing process and cost concerns will be evaluated

vi. Prototype Development

A simple and low cost prototype will be built up based on the final solution. The size and materials used in the prototype will not identical to the actual product due to budget.

vii. Report writing

All the study and knowledge regarding design and development of vacuum forming machine will be recorded in the paperwork for future reference.

The methodology of this study is summarized in the flow chart as shown in Figure 1.1.

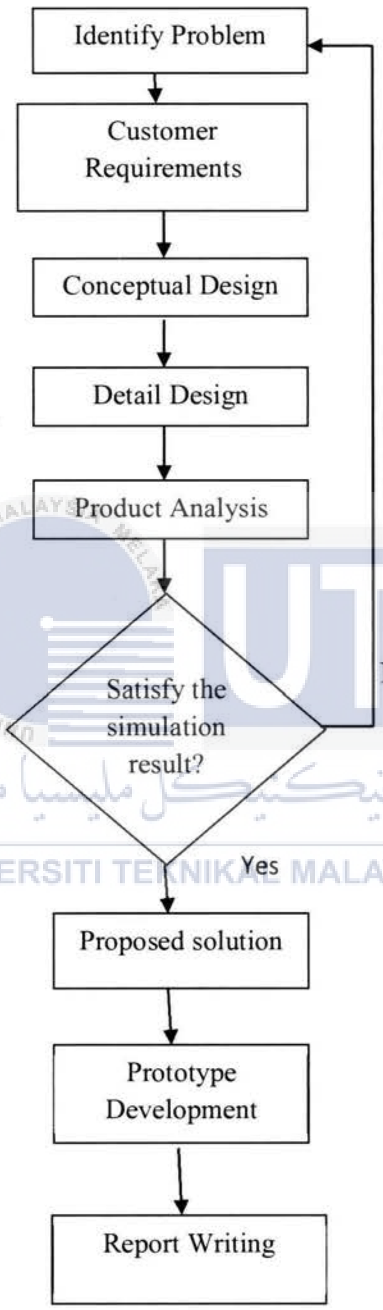


Figure 1.1: Flow chart of the methodology

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF VACUUM FORMING

In 1940's and 1950's, the vacuum formed plastic was developed from a line of vacuum casting and moulding technologies. In that time, vacuum formed plastic was the first exhibition and marketing tool. After that, a series of vacuum moulding machine was introduced until a plastic sheet vacuum forming machine was lastly accomplished and patented in year 1964. However, the application of vacuum in removing the excess air was not strong enough to change the shape of the plastic permanently. There were bubbles trapped inside the inner part of the formed part, which weaken the product.

By the 1970's the technology was improved with a patent in 1974. In patent 1974, the vacuum moulding apparatus was improved because the distance between the heater and the plastic is adjustable. The user can move the heater near to the plastic frame to soften it. Besides that, a forming board was designed and created as a place to put the mould. A vacuum system was also designed for removing air from the space between the forming board and a softened plastic sheet. The wood frame and plastic sheet could be raising and lowering with channels for guiding air flow out of the system so that the sheet is quickly pulled onto the mould. Until today, the vacuum forming machine is still undergoing a series of modification in order to enhance the method and equipment for a perfect outputs which fulfills customer's requirements from time to time.

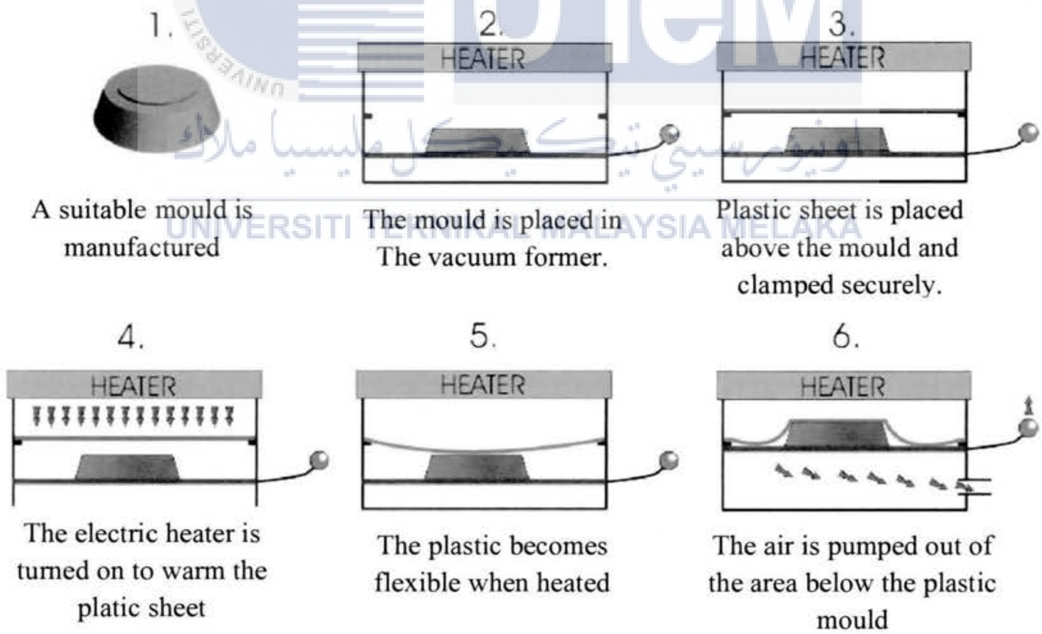
In fact, vacuum forming process is almost same with thermoforming process. Thermoforming is a manufacturing process which fabricates plastic enclosures by preheating a flat plastic sheet and then pressing it into a mould whose shape it takes. There are many ways to perform thermoforming; it can be done by vacuum, pressure, and direct mechanical force. This process offers close tolerances, tight specifications, and sharp detail for custom plastic parts. The difference between vacuum forming and thermoforming is that the vacuum forming has an additional process where the vacuum is used to conform plastic to the mould during forming. Therefore, vacuum forming can be considered as a simplified version of thermoforming.

2.2 WORKING PRINCIPLE OF VACUUM FORMING MACHINE

Vacuum forming works on the principle of softening a thermoplastic over a mould and removing air, creating a temporary vacuum which forces the soften plastic over the mould and form a product permanently. Figure 2.1 shows the sequence drawing of vacuum forming process.

From Figure 2.1, first, a mould is designed and fabricated by following the suitable design criteria of mould. The material of the mould can be made of soft wood, Aluminium, Plaster and other. The material selection for the mould depends on the severity and the length of service required. If the quantity of product is less and the temperature of plastic is low, then wood and plaster would be preferable. Besides than materials selection, the part design of mould needs to be taken into consideration in order to fabricate a vacuum formed product with good surface finish. It is advisable that the edges or sides of mould are shaped at a draft angle (minimum of 3 degree) to easily remove the plastic product from the mould.

Then, the mould is placed on the platen which is located in the bottom part of the vacuum forming machine. A thermoplastic sheet is clamped in position above the mould and below the heating source. Next, an electric heater is turned on to warm the thermoplastic sheet. The thermoplastic reaches its forming temperature and ready to form when it is seen to warp or distort. After that, the heater is turned off. The forming process can be performed by lifting the mould to the heated plastic or moving the heated plastic downward to the mould. Once the thermoplastic mould reaches the thermoplastic, the vacuum is turned on, sucking all the air beneath the plastic sheet. The vacuum pump is switched off when the plastic is cooled. Next, the plastic sheet is removed from the clamped frame and then trimmed to the desired shape.



(V.Ryan © 2001-2009)

Figure 2.1: Sequence Drawing of Vacuum Forming Process

2.3 THE FUNCTION OF VACUUM FORMING MACHINE' PARTS

2.3.1 Clamping Frame

In vacuum forming machine, a clamp frame is needed in order to hold plastic sheet firmly during the forming process. It can be simply made by joining two metal frames on a hinge that trap the sheet between them. Normally there are some cone shape objects welded on the inner surface of the clamp frame that are in contact with the plastic sheet, in order to prevent the plastic goes out from the frame during the forming process. After plastic is heated to proper temperature, the hot plastic will be pressed on the mould. Most vacuum forming machine in marketplace has a clamping system that is attached to a shuttle cart. The shuttle cart covers heating elements and supported by a metal wheel that fit into a track. It is used to prevent the clamping frame from sliding down. Pneumatic cylinders are used to move the cart into or out of the oven area to forming area. However, the clamp frame and components inside the cylinder will be easily worn out due to frequent exposure to heating and cooling. (Boser, 2003)

2.3.2 Platen

Platen is a framework used to move a mould up and down. It gives the user enough clearance to pull the clamping frame across the mould and to prevent dragging the hot plastic against the mould surface. Three are 4 common methods to move the platens, which are pneumatic, hydraulic, rack and pinion drive and do it manually. For the pneumatic method, it has a cylinder attached to the platen and can be moved by actuating the air valve. It is simple, cheap, and easy to be installed and operated. However, it doesn't perform immediately and requires certain large force to move a heavy mould. For the hydraulic system, it is accurate and has enough of power compare to pneumatic. The only disadvantage of this system is that it requires a constant period of maintenance to prevent oil leakage from the system. For rack and pinion platen, or known as electrical driven platen, it also has enough power and high accuracy, it can stop the platen at the exact position at each time. However, this system is quite expensive compared to the previous system. The last method is by moving the platen manually, this method doesn't need any cost but require good alignment. (Boser, 2003)

2.3.3 Heating Site

It is the location or chamber where heat is generated in order to soften the plastic. Plastic can be heated by any type of heat sources which are conduction, convection ,and radiation. Heat Conduction is heat transfer between the solid when temperature difference exists. Heat Convection is heat transfer by mass motion of heated fluid such as liquid or gases .Radiation is the transfer of internal energy in the form of electromagnetic waves. In order to heat up the plastic to desired properties, the portion of spectrum should be taken between 0.1 to 100micron because this is portion where high radiation energy is given out form heater. The radiation energy and its wavelength can be determined from the heater temperature and its exposed surface area. (Boser, 2003)

2.3.4 Vacuum Site

It is the place or chamber where trapped air between the plastic sheet and the mould is drawn out, in order to conform the plastic. The vacuum can be generated by using vacuum cleaning machine or vacuum pump. With a large volume capacity of vacuum pump, this enables the rapid moulding of the heated sheet before the plastic sheet temperature drops below its ideal forming temperature.

2.4 VACUUM FORMING TECHNIQUES

There are many different vacuum forming techniques that can employ in the thermoforming process. The type of technique you choose will be determined by the geometry and shape of the part you are trying to make, along with the degree of difficulty of the part, and what your equipment is capable of doing.

2.4.1 Drape forming

Drape forming is a technique where a piece of sheet plastic is clamped in some type of clamping mechanism, then put into a heating oven and heated up to the desired temperature. After the plastic sheet is softening, it will be retracted from the oven and draped over a mould. The sheet will be trapped inside the clamping mechanism over the edge of the mould flange, while a vacuum is applying to the mould chamber. Figure 2.2 shows the process of vacuum Assisted Drape Forming. Firstly, a clamped PALSUN sheet will be heated until soften. Next, the sheet will be pulled over the mould until the sheet has formed a seal around the mould. At the meanwhile, a vacuum is drawn to pull the sheet against the mould surface. Lastly, the sheet will conform perfectly to the shape of mould. (Boser, 2003)

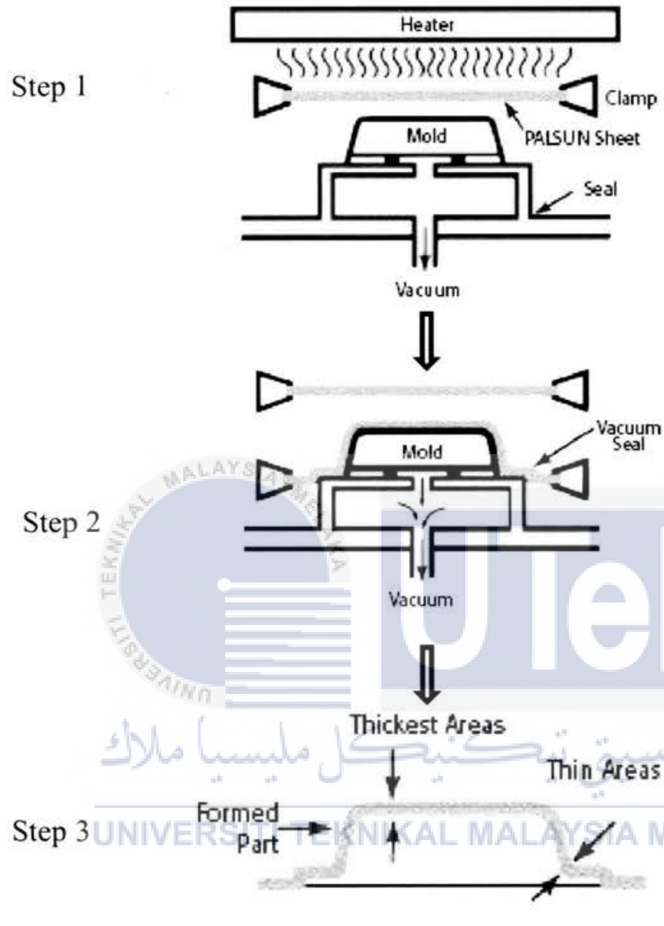


Figure 2.2: Process of Vacuum Assisted Drape Forming

2.4.2 Plug Assist forming

A plug is a mechanical device used to achieve good wall thickness when forming into deep cavities. It is made up of an insulator and covered with soft cloth material in order to prevent itself from picking up the plug marks when the plastic in the hot state. Pug Assist forming is a forming technique which is very similar with the Drape forming .All the steps happen in Plug Assist forming are same with Drape Forming until just before applying the vacuum. In Plug Assist technique, hot plastic must be pushed into various pockets, ribbed cavities, and steep-walled sections before applying the vacuum. The objective of this technique is to allow the extra plastic move down to the bottom of these areas before thinning. Therefore, it can form a product with better shape compared to the Drape forming. However, this technique would be difficult to employ manually. The operator must be able to control the distance between top and bottom platens in order to prevent them from smashing to each other. Figure 2.3(a) and Figure 2.3 (b) show the product of Drape forming and Plug assist forming. From the figure, it is obvious that product of plug assist forming has more uniform thickness when compared to the Drape forming. Besides that, complex products can be made by using Plug Assist forming technique. (Boser, 2003)

Figure 2.3(a) Product of Straight Drape Forming

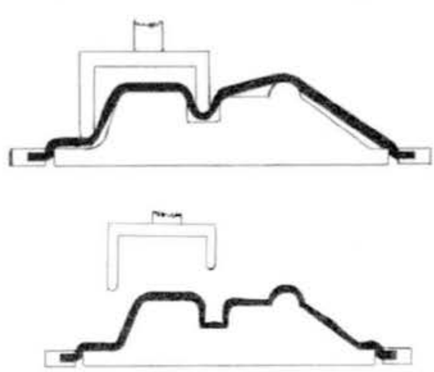


Figure 2.3 (b) Product of Plug Assist Forming- Plug Extended

2.4.3 Snap back forming

Snap back forming is a forming technique when the heated plastic sheet must be pre-stretched before brought into contact with the mould. Figure 2.4 shows the sequence of snap back forming techniques. First, a clamped and heated plastic sheet is brought into the forming area. Vacuum is applied to the vacuum box and the plastic sheet will be pulling downward and forming a hemisphere shape. The mould, which is on the top platen, is lowered into the hemispheric shape of the sheet. The vacuum inside the vacuum box will be turned off and the vacuum will be applied to the mould chamber. Once the vacuum is applied to the mould chamber, the sheet will snap up against the mould surface quickly and a mould product is formed. (Boser, 2003)

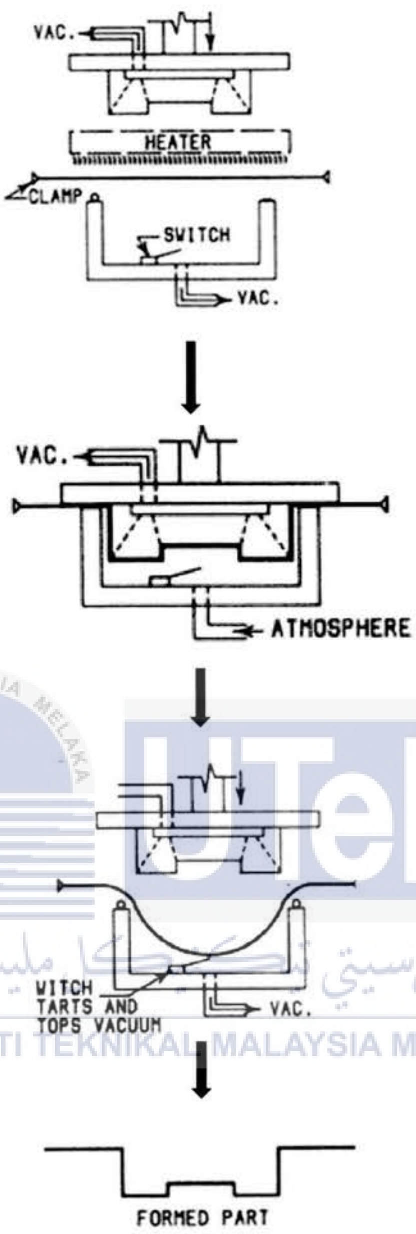


Figure 2.4: Sequence of snap back forming techniques

2.4.4 Billow Forming

Billow Forming, can be known as bubble or free forming, is a forming technique where can only be done on a limited number of thermoforming machine. This process can only be implemented by well-trained personnel because the procedures involved in this process are complex. Figure 2.5 shows the billow forming process with plug assist. In this process, a female mould is placed in the bottom plate of the vacuum forming machine. A heated and clamped plastic is located in the forming station. Air will be blown through the vacuum hole in female mould to form a bubble over the cavity of the female mould. When the bubble reaches maximum desired height, the plug assist will penetrate the hot plastic bubble and at the meanwhile, air will be exhausting out from the mould cavity. How good the hot plastic billow around the plug depends on how fast air is bleeding out from the mould cavity and how fast the plug extends to the mould cavity. This is a complicated thermoforming process which requires accurate set-up and timing during extension of plug assist and evacuation of air from mould cavity. If implement this process properly, one can produce the most uniform material distribution over large area of complex part (Boser, 2003)

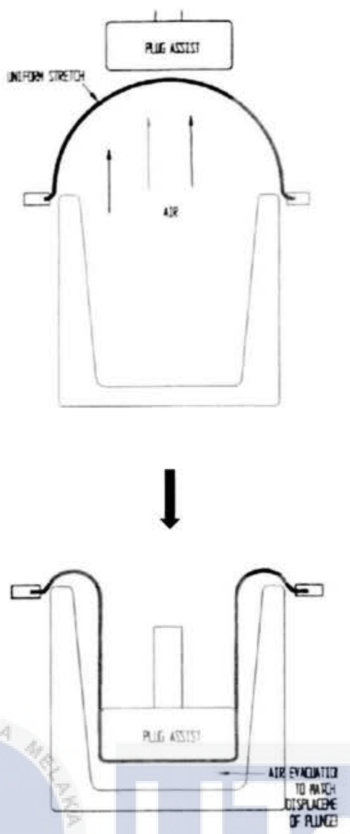


Figure 2.5: Billow forming process with plug assist

2.5 DRAW RATIO

Draw ratio or known as stretch ratio, is the amount of surface area covered on the mould divided by the amount of material that is available to be used. In other words, draw ratio is the relationship between the beginning surface area of the unformed sheet which covers the opening of a feature, and the ending surface area of the interior of the feature once formed. Draw ratio can be showed numerically if the surface area can be calculated. (Boser, 2003)

2.6 TYPE OF PLASTIC MATERIALS

2.6.1 Thermoset and Thermoplastic

There are two fundamental groups of plastic materials which are thermoset and thermoplastic. Thermoset is a synthetic material that strengthens during being heated. Once they have undergone the initial heat-forming, they cannot be melted or remoulded. In contrast to thermoplastic, which soften when heated and harden and strengthen after cooling. Unlike thermoset, thermoplastic can be heated, shaped and cooled many times without chemical change. Besides that, thermoplastic can be formed easier than thermoset. Therefore, thermoplastic is more suitable for thermoforming process.

2.6.1.1 Type of Thermoplastic

However, thermoplastics can be split into two different groups, which are amorphous and crystalline. Amorphous thermoplastic contains a random arrangement of molecules whereas crystalline thermoplastic contain well-arranged molecules. Amorphous thermoplastic is easier to be thermoformed because they do not have critical forming temperature. When heat is applied to amorphous material at Glass Transition temperature, it will become soft and easy to bend. When the heating temperature reaches viscous state/rubber state, the material can exhibit large elongations under relatively low load. Amorphous thermoplastic has wide forming range because their property changes over a range of temperature. Examples of amorphous thermoplastic are Polystyrene and ABS. For Crystalline materials, they have a relative critical forming temperature because they go rapidly from Glass transition state to viscous state. Thus, heating temperature need to be controlled accurately in order to thermoform the material. Examples of Crystalline materials are Polyethylene and Polypropylene .Figure 2.6 shows the changes of property of amorphous and crystalline thermoplastic changes over a range of temperature. Thus, amorphous material is an ideal to be used in thermoforming process when compare to crystalline materials. This is because the forming temperature range for amorphous materials is wider than crystalline materials. Table 2.1 shows the most used amorphous and crystalline materials and their respective temperature. (R.Rosen, 1930)

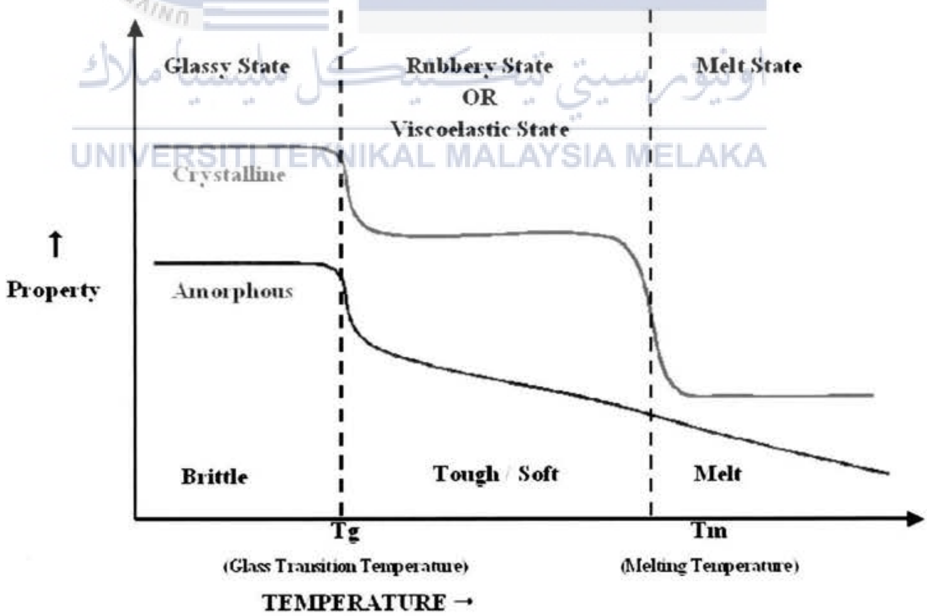


Figure 2.6: Property of amorphous and crystalline thermoplastic changes over a range of temperature.

Table 2.1: Amorphous and crystalline materials and their respective temperature

Material	GlassTransition Temperature (tg)	Rec.Mould Temperature.	Rec.Forming temperature	Drying Temp
PS	94 °C	82 °C	150 -175 °C	70°C
ABS	88-120 °C	82 °C	150 -180 °C	70/80°C
PP	5 °C	90°C	150 - 180 °C	65°C
Acrylic/PVC	105 °C	-	140 - 190 °C	75°C
PC	150 °C	127 °C	170 - 205 °C	90°C

(Formech International Ltd , n.d.)

2.7 TYPE OF MOULD

There are basically two types of mould ,which are male(positive) and female(negative). Male and female mould are shown in Figure 2.7 and Figure 2.8 respectively. By using a male mould, the plastic is stretched over the mould, and then vacuum is applied to draw the plastic down onto the surface of the mould. However, by using a female mould, the plastic is drawn down into a cavity by the vacuum. One of the major differences between male and female mould is the thickness distribution of the wall. In forming process, female mould will produce product with thickest walls but thinnest bottom whereas for male mould, it will produce product with the thickest bottom and thinnest walls. This thinning effect will be more obvious if the depth of mould cavity is much deeper than its diameter. Thus, female mould will produce a much thinner part toward bottom whereas male mould will produce much thinner part at bottom corners. Figure 2.9 shows the thinning effect of female and male mould during forming process.

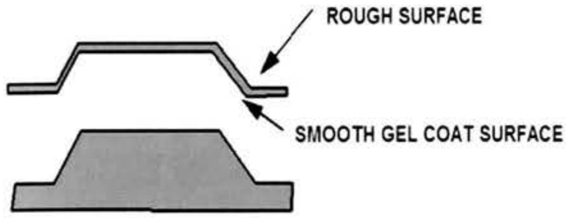


Figure 2.7: Male mould

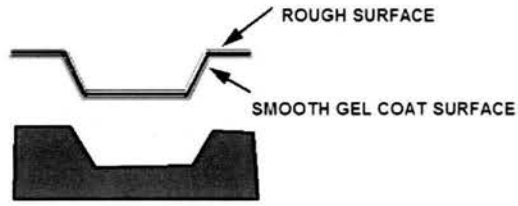


Figure 2.8: Female mould

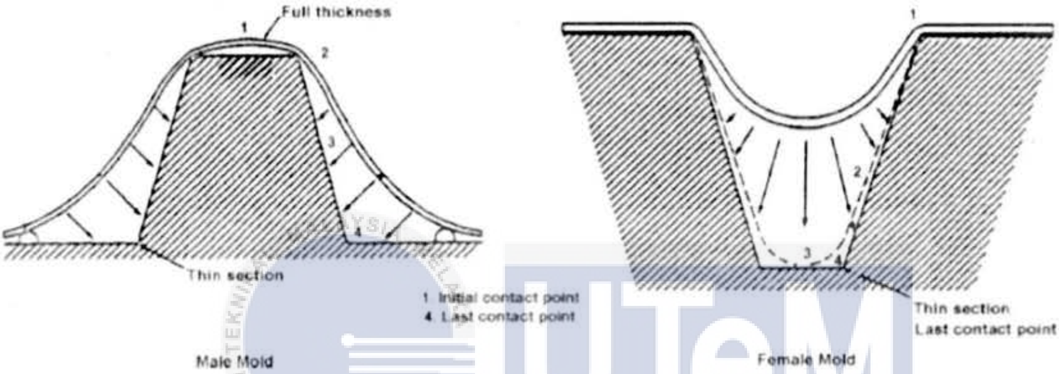


Figure 2.9: Thinning effect of female and male mould during forming process.

2.8 PATENTS FOR VACUUM FORMING APPARATUS

In 1936, E. L. Helwig of Rohm and Haas Company in Philadelphia, an acrylic resin manufacturer, has two patents using different techniques in forming acrylic. Figure 2.10 shows a patent 11-27-1936 using hot oil pressure for forming acylic. Figure 2.11 shows a patent 8-28-1942 using snapback forming. (R.Rosen, 1930-1950)

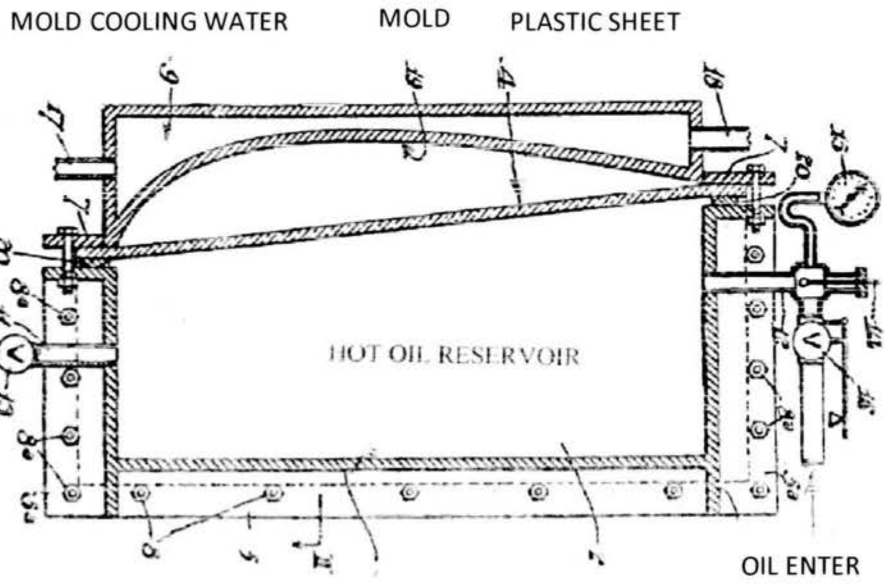


Figure 2.10 H.E.Helwig of Rohm and Haas Corp filed for a Patent 11-27-1936 using hot oil pressure for forming acrylic

Figure 2.10 presents the forming of canopy from a pre-heated sheet of acrylic forming which utilizes a hot fluid under variable pressure .In order to prevent the plastic sheet being marred against the mould surface when forming process, the mould was water cooled so that the sheet would chill and become strong. Besides that, the inner surface of the sheet would be free of blemishes since it only has contact with the hot fluid. This process is similar to a modified method used today where air pressure forms sheet against a temperature-controlled mould producing high-quality parts. (R.Rosen, 1930-1950)

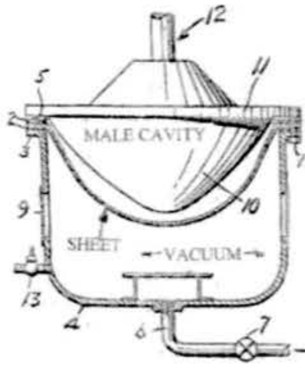


Figure 2.11(a)

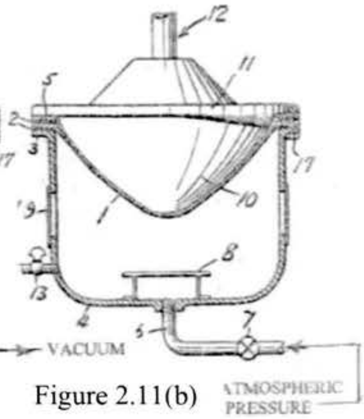


Figure 2.11(b)

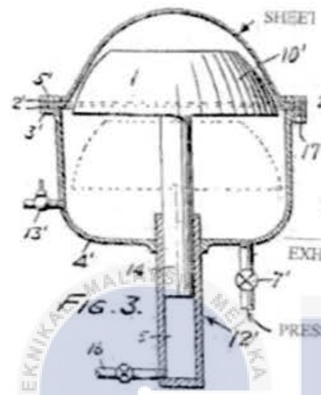


Figure 2.11(c)

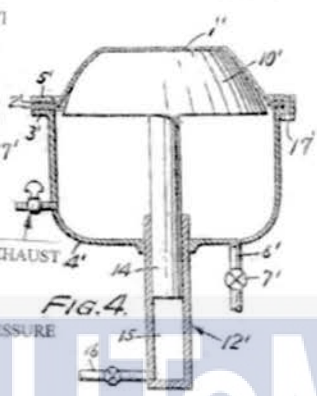


Figure 2.11(d)

Figure 2.11(a) to Figure 2.11(d) : H.E.Helwig filed for Patent 8-28-1942 using snapback forming

Figure 2.11 illustrates a male snap-back technique using an oven-heated acrylic sheet which is clamped to the device with quick-acting clamps. Figure 2.11(a) and Figure 2.11(b) show the use of vacuum to pre-stretch the hot sheet and then allow atmospheric pressure to force the hot plastic against the male cavity. Figure 2.11(c) and Figure 2.11(d) show the use of air pressure to expand the surface of the hot sheet before it snaps back to cavity. This process can produce a product with uniform wall thickness. (R.Rosen,1930)

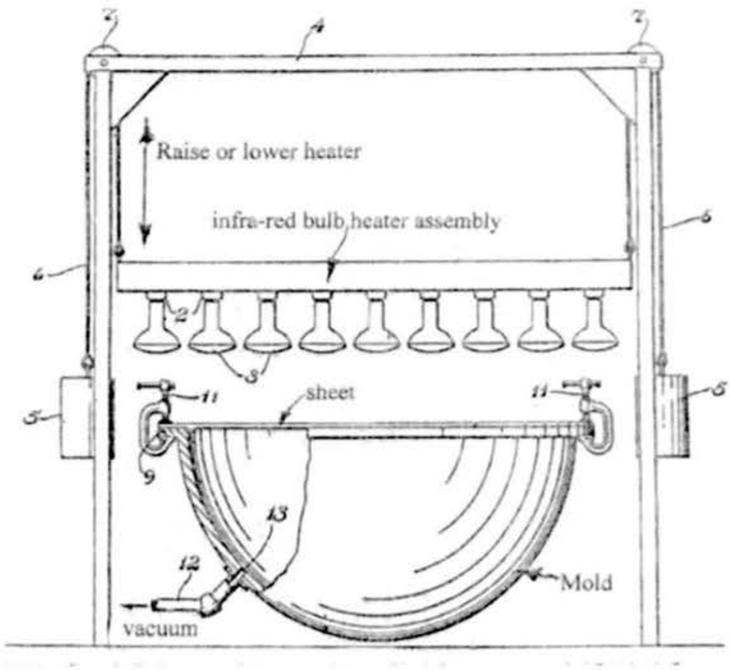


Figure 2.12: R.E.Leary of Dupont Corp filed for Patent 12-27-1940 for a vacuum forming apparatus.

Figure 2.12 shows a patent for a vacuum forming apparatus which was filed by R. E. Leary of Dupont Corp in 12-27-1940. He used two methods to control the radiant heat source to produce a uniform wall thickness product. The heat supplied to the plastic sheet can be well controlled by adjusting the distance between the heater and the plastic sheet. Each lamp in the heater is individually controlled in order to achieve uniform temperature distribution across the sheet. This patent suggests the use of radiant heating at the forming site rather than preheating the sheets in an oven and later transporting them to a mould. The embedded heating element in the machine is convenient to users and can prevent heat loss during forming process (R.Rosen, 1930)

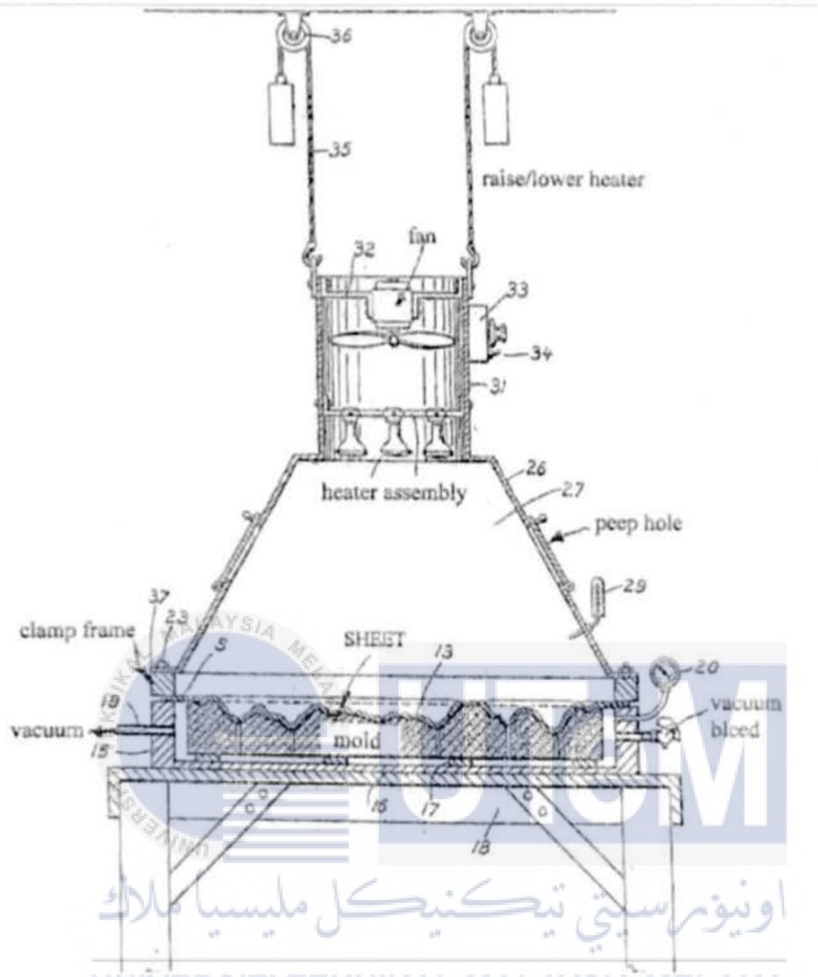


Figure 2.13: Patent 9-24-1946

Figure 2.13 shows a patent of a system for vacuum forming plastic relief maps, which is filed by J.J.Braund on 9-24-1946.This system, is analogous to R. E. Leary's radiant heat oven, except the heat transfer method. This system has a fan above the heater assembly, which is used to transfer heat by convection but not radiation. According to Braund, it can create a uniform sheet temperature for the sheet before forming process. (R.Rosen, 1930)

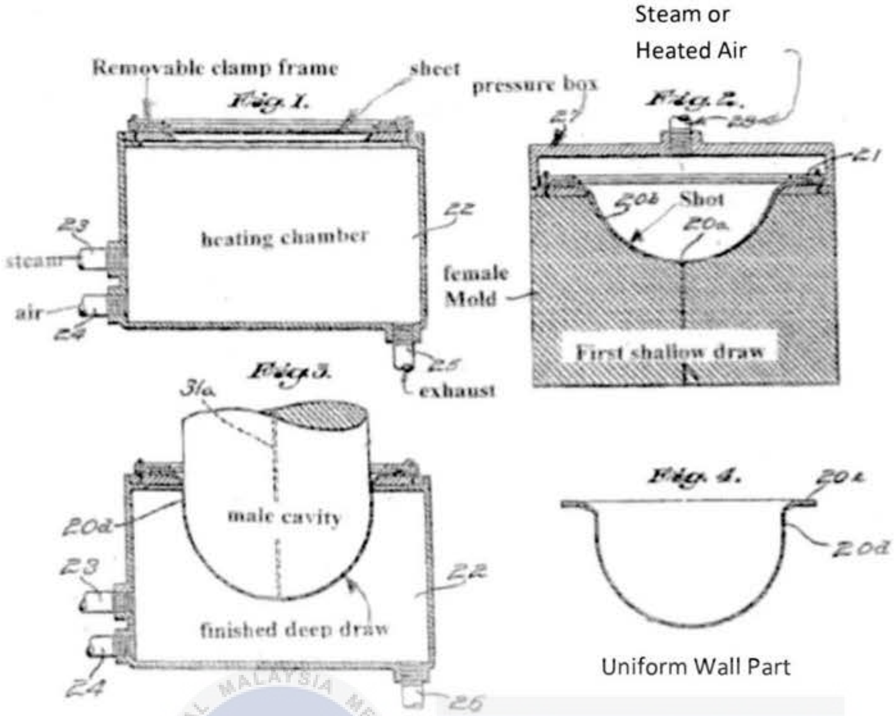


Figure 2.14: F.E.Wiley of Plax Corp filed for Patent 6-1-1944for a method of deep drawing plastic sheets

Figure 2.14 shows a patent for a method of deep drawing plastic sheets, which was filed by F. E. Wiley of Plax Corp., Hartford, Connecticut on 6-1-1944. There are 3 steps process in this system which are preheated, shallow depth forming in a female cavity and followed by deep drawing on the male cavity. The steam acts as the heating element in this system; it raises the sheet to the forming temperature in all steps. The clamp, which holds the sheet, can be moved manually from step to step. (R.Rosen, 1930)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the methods that are used throughout the project are described. Besides that, the methods and steps to obtain outcomes of the project are explained in details.

3.2 ENGINEERING DESIGN PROCESS

Engineering design process is an iterative decision-making activity, to produce plans by which resources are converted, preferably optimally with due consideration for the environment into systems and devices (products) to meet human needs. In other words, engineering design process is a series of steps that engineers follow when they are trying to solve a problem and designing a solution for something. However, engineers do not always follow the engineering design process from A to Z, they can simply design and test a product when the ideas come and then only go back to earlier step to find the problem and make a modification to their design. The main goal of the process is to find a solution for a problem, thus the middle steps can be varied. Engineering design process is an iterative process because this process can go on for a very long time until the design engineers stop thinking of new ideas and looking problem with their design. Figure 3.1 shows the steps of engineering design process that will be used in this project.

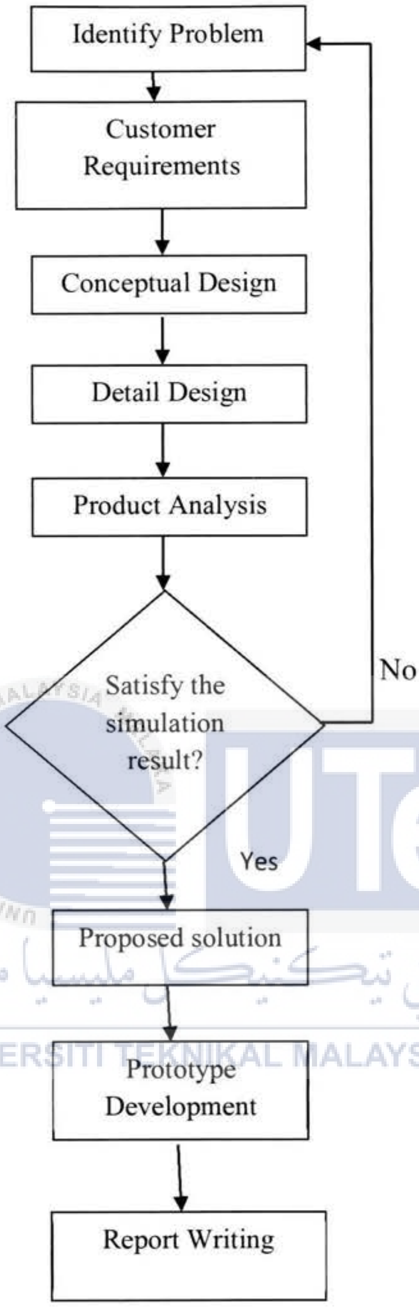


Figure 3.1: Flow chart of the methodology

3.2.1 Identify Problem

This is the most important step in the design process. With fully understanding the problem can help engineer solve it successfully. In many cases, problems presented to engineers are not specific. Thus, engineer needs to clearly identify every aspect of the problem on which attention should be concentrated.

3.2.2 Background Research

After coming out with a clear and exact problem statement, engineers will do background research on the problem their solving. They will find out the similar problem faced by others and how they solved it. Besides that, engineers will also gather information on the environment they're dealing with, the situations their solution will be used in, and the ways it will be. Background Research is a significant part of engineering design project as engineers can learn from the experience of others and prevent themselves from making the same mistake as others. There are 4 steps that engineer need to go through in order to complete a background research.

i. Determine requirements or comment of the target user.

ii. Find out the existing product that may solve the current problem or similar problem.

iii. Understand the working principle of the product and the ways to make it.

iv. Discuss or exchange ideas with experienced people, in order to know which area of science cover the project.

3.2.2.1 Market analysis

Customer's requirement can be determined by conducting market analysis. In this product development process, market research is conducted initially to assess market potential;, market segments, and product opportunities and to provide production cost estimates and information on product cost, sales potential, industry trends and customer needs and expectations. (Haik and Shahin ,2011)

Market analysis must be conducted at the early stage of the design process in order to prevent engineers from wasting unnecessary money and time in the product development process. There are two different methods can be used in market analysis which are direct search and indirect search. Direct search is a technique where information is obtained directly from people whereas indirect search is a technique where information is obtained public sources. In this project, direct search technique will be used because the information is collected by conducting a group interview. During the group interview, the interviewee will be asked several questions about the product, for example, what is their desired design for vacuum forming machine and what is the existing problem of vacuum forming machine in the marketplace.

3.2.3 Customer Requirement

Customer needs are merely a wish list provided by customers. Thus, in order to apply their need into a new product, engineers must translate all the customer need to engineering characteristic. Engineering characteristic is a set of specification that identifies how the product will function from a technical standpoint. In other words, Engineering characteristic is a set of physical properties whose value determine the form and behaviour of design, including the feature of the design and values to describe the performance. Once a list of requirements has been established, engineers need to interpret and prioritize all the needs into product requirements, which yield the final objectives of the product. The importance of the requirement can be determined by setting the scale from 1 to 10, where 1 is the least important and 10 is the most important.

3.2.3.1 Objective tree

In this report, an objective tree is developed in order to organize the objectives of the design. The objective tree technique helps to define product objectives and provides a way to order them in a hierarchical structure. Besides that, it allows a clear and concise method in representing the requirements of the project to be carried out. There are some procedures in developing the objective tree .First, generate an initial list of design objectives. Then, identify an overall objective of the design, to which all other objectives will relate. The overall objective will be positioned at the 1st level of the tree. Next, other objectives for the next level down will be selected and added below the main objective. The branching rule is used to connect between parent objective and its children objective. Figure 3.2 shows the example of objective tree. From Figure 3.2, it was known that the 1st level of the objective tree is objective A and objective B, which is the overall objective of the design. There are also sub-objectives under the overall objective, which are sub-objective A1, sub-objective A2 ,and sub-objective B1. All the sub-objectives are added below their parent objectives. For example, sub-objective A1 and sub-objective A2 are positioned below objective A; sub-objective B1 are positioned below objective B. The objective tree is ended when there is no more sub-objectives can be added to their parent objective.

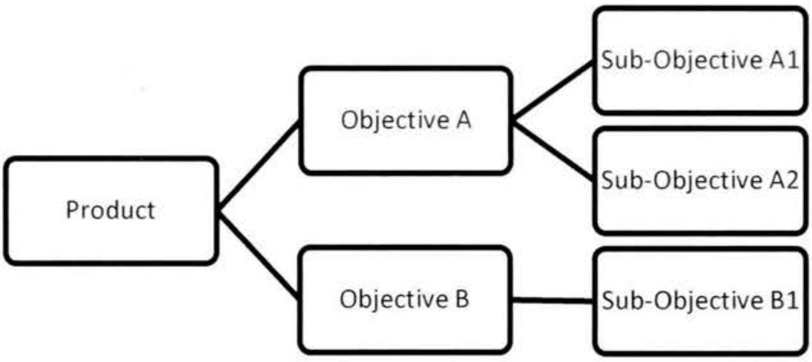


Figure 3.2: Example of objective tree.

3.2.3.2 Functional Analysis

In functional analysis, product components and their functions can be identified by breaking down the product function into sub-functions. Function is independent tasks which describe what a product will do. Sub-function is the function of component in a product that has to work in order for a more general function to perform. There are several methods that engineer can use to carry out functional analysis, such as functional decomposition, reverse engineering ,and value engineering. In this project, functional decomposition will be used. Function decomposition is a technique that engineers use to describe a set of steps in which they break down the overall function of device, system, or process into its smaller parts. The functional structure of product can be represented in overall function diagram or known as black box diagram. A block diagram consists of all sub-functions separately identified by enclosing them in boxes. Besides that, it illustrates the overall function of the product along with inputs and outputs to the system. Figure 3.3 shows an example of black box diagram.

There are several steps to carry out functional decomposition of a design and representing it as a functional structure. First, identify the most general task of the product; the function must reflect the overall purpose of the design. Then, draw a big box represent the general function of the product. After that, draw an input arrow pointing to the big box and an output arrow point out from the box. This represents the relationship between input and output regardless of the solution within the box. Next, identify the different level of sub-functions. Draw small boxes represent each of the sub-functions and put it inside the big box. Then, draw an arrow between all the sub-functions to show the relationship between the sub-functions of the product.

Figure 3.3: Sample Black box diagram

From figure 3.3, it was known there are 2 small boxes bounded inside a big box. The big box is the general function of the system and the small box is the sub-functions of the system. The overall system function is the combination of sub-functions which are sub-function 1 and sub-function 2. To perform the function of the system, 1st an input is required to perform sub-function 1 and sub-function 2, then finally yield the output.

3.2.4 Conceptual Design

Conceptual design is a preliminary drawing showing ideas that have been formulated after gaining some information from the customer. Other than that, a conceptual design can also be called as a description of a proposed system in term of sets of integrated ideas and concept about what it should do, behave and look like. Conceptual design plays an important role in the design phase and it should be done well before embodiment design phase to ensure everything is done right in the other phase afterward. In developing concept design, first, we should understand the root problem addressed by the customer requirements, the requirement and the reason they are qualified as requirement. Then, we should identify and explore a broad range of alternative solutions that can solve the root problem and requirements. Those alternative solutions should be evaluated and analysis in order to come up with the best solution that can fulfill all customer's requirements as well as the business objectives and limitations. Undoubtedly, it is important for us to know the goal of the conceptual design phase is to identify and select the general type of solution without considering the implementation details. The final conceptual design serves as a common roadmap for each of the technical disciplines as they embark on the subsequent detailed design. There are lots of benefits when applying the conceptual design in our process of development of the product. It can ensure we are solving the right root along the whole process and decrease the time to market and the product cost.

3.2.4.1 Morphological chart

A morphological chart is a table that generally developed as an analysis tool for a design concept. It is also a method to organize all the concepts to build suitable arrangements to achieve the overall function of the product. The chart consists of two sections. One of the sections is used for listing the functions and sub-functions of design, while another section is for the various options of design to produce specific function. Therefore, it is a visual aid in leading designers to come out with different ideas for a better product. Usually, a morphological chart is used in design meeting in order to include all the possible ideas or concepts generated from each individual. This morphological chart is a useful tool in encouraging more individuals to be effective in creative thinking, creative attitude and confidence when providing ideas or solution for the design. Table 3.1 shows the schematic of a morphological chart; all the sub-function are shown in the left column and all the possible solutions are shown in the corresponding rows.

Table 3.1: Basic structure of a classification scheme with the sub-functions of an overall function and associated solutions

Possible Solution/ Options / Sub Function		1	2	...	j	...	m
1	F_1	O_{11}	O_{12}		O_{1j}		O_{1m}
2	F_2	O_{21}	O_{22}		O_{2j}		O_{2m}
:		:	:		:		:
i	F_i	O_{i1}	O_{i2}		O_{ij}		O_{im}
:							
n	F_n	O_{n1}	O_{n2}		O_{nj}		O_{nm}

(Haik and Shahin 2011)

There are several steps to develop concepts from the function with the aid of the morphological chart. First, generate all the possible sub-solution for each of the sub-function of the product or system. Then draw up the chart containing all of the possible sub-solutions. Each row represents all the possible sub-solutions for the particular sub-function. The sub-solution can be presented in word form or graphic form. After fill in all the possible sub-solution for each sub-function, the morphological chart contains the complete range of all possible solutions for the product. A complete conceptual design can be generated by selecting one sub-solution at a time from each row and combine those selected concepts into a single design. Table 3.2 shows the Example of Morphological Analysis.

Table 3.2: Example of Morphological Analysis

Criteria	Option 1	Option 2	Option 3	Option 4
Criteria A	Concept A1	Concept A2	Concept A3	Concept A4
Criteria B	Concept B1	Concept B2	Concept B3	
Criteria C	Concept C1	Concept C2	Concept C3	Concept A
Criteria D	Concept D1	Concept D2	Concept D3	

Concept Design 1

3.2.4.2 Concept Evaluation

Pugh's evaluation matrix and the decision matrix are the method which can be used by an engineer to decide systematically between different concept designs. Both methods are based on comparing alternatives with the list in the specification table. In other words, it helps engineers in design decision by establishing a procedure to choose the best design from the considered designs. In this project, decision matrix will be used to choose the best concept design among others.

i. Decision Matrix

Unlike Pugh's evaluation matrix, decision matrix utilizes a more numerical approach. All the design criteria are ranked according to their importance and then each concept is rated against each design criteria. The design concept with the highest weighing is the best solution among others. There are several steps to conduct the concept evaluation by using decision matrix. Table 3.3 shows the example of Decision Matrix. First, a list of the criteria that needs to be compared between different types of designs concepts. All the criteria are developed from the customer needs and engineering characteristics. Then, the weight factor for each criterion is established. A number between 1 and 10 are set as the range for each criterion, 1 is the lowest and 10 is the highest scale. After that, a concept design is chosen as the datum, or a reference concept with which all other concepts are compared.

Table 3.3: Example of Decision Matrix

No	Specification	Weight (1-10)	Concept design 1	Concept design 2	Concept design 3	Concept design 4
1	Specification A					
2	Specification B					
3	Specification C					
4	Specification D					
	Total +					
	Total -					
	Total s					
	Overall score					
	Weight Overall score					

Then, each design concept is evaluated by comparing with the datum in term of each criterion. In each comparison, if a concept design is evaluated better than datum, a "+" is given, if it is worse than datum , a "-" is given, and if it is same as datum, a "s" will be given. The suitable symbol will be input into the cell of the matrix. Then, the sums of the "+","-" and "s" ratings are calculated for each concept. Thus, the overall score on each design concept is determined by calculating the sum of "+","-" and "s". Since the criteria have different weights on meeting customer needs, these weights are considered in the weighted overall score. From the results of the weighted score, we can easily determine which design concept is the best.

3.2.5 Detail Design

Detail design is the phase where the design is refined, specification and estimation are created. It is a final step to be carried out before the product is manufactured and tested. In this phase, detail design skill is needed to estimate the requirement of the product in a reasonable way and refine the product to ensure the plan under cost estimation. It is a very important step because it ensures the overall design solution satisfies the project objective.

3.2.5.1 CAD drawing

In this project, the vacuum forming machine is drawn by using CATIA V5R20. The assembly of both designs are displayed in forms of isometric view and exploded view. Apart from that, the detailed drawings are also provided in this project. All the drawings will be appended in the Appendix at the end of the report.

3.2.6 Product Analysis

Once the product is well defined, a complete analysis is conducted. In the analysis process, the integrity of the design in terms of its safety, material, manufacturing process and cost concerns will be evaluated. In every design process, the researcher needs to select the suitable material for the product as well as the manufacturing process to be used to fabricate the product. In order to select the best material which fits the design requirements, the researcher must have known the characteristic, the properties of the materials and the method in which they can be shaped. Besides that, manufacturing process of different parts of the product also need to be considered in detail design stage. Manufacturing process is the process of transforming raw material into a final product. Thus, selection of suitable materials and manufacturing process for different part of the product will be covered in this project. Besides that, the cost analysis of the product is also carried out to generate a rough estimation of product cost.

3.2.7 Prototype Development

Prototype Development is the experimental phase of the engineering design process. In this phase, all the paper drawings are transformed into hardware in order to verify the concept's workability. In this stage, the prototype is built, tested and then reworked as necessary until satisfied results are obtained. Besides than Prototype, there are three other construction techniques available for hardware development, which are Mock-up, Model, and virtual prototyping. Comparing among other techniques, prototype is the most expensive technique because it is constructed at full-scale with an actual working physical system.

3.2.8 Report Writing

All the study and knowledge regarding design and development of vacuum forming machine will be recorded in the paperwork for future reference.

CHAPTER 4

Conceptual Design

4.1 CUSTOMER'S REQUIREMENTS

After a problem is identified, researchers need to make sure that the product they are developing, match the people's needs. Therefore, market analysis is carried out to identify and clarify the customer's needs. Market analysis is done by searching the other relevant product in the market and identifies the existing problem in the product. To identify customer's need is very important in any design process; therefore, a market analysis should be conducted at the early stage of product development process. In this research, several possible customers were called to focus group interview discussing their requirement about the developing product. Table 4.1 shows the customer's requirement on the vacuum forming machine during interview section

Table 4.1: Customer's requirement on vacuum forming machine

Easy to operate	Easy to install and uninstall	Average size
Simple	Internal parts totally enclosed	Low maintenance cost
Manual	Easy to access interior	Low manufacturing cost
Light weight	Ability to stop in mid operation	Safe to operate
Several part count		

4.2 OBJECTIVE TREE DIAGRAM

In order to see a clear arrangement of customer's requirement, all the customer requirements are organized in an objective tree, which helps clarify the objective of the design. An objective tree represents the requirement of product in a more clear and concise method. Figure 4.1 shows the objective tree diagram of vacuum forming machine

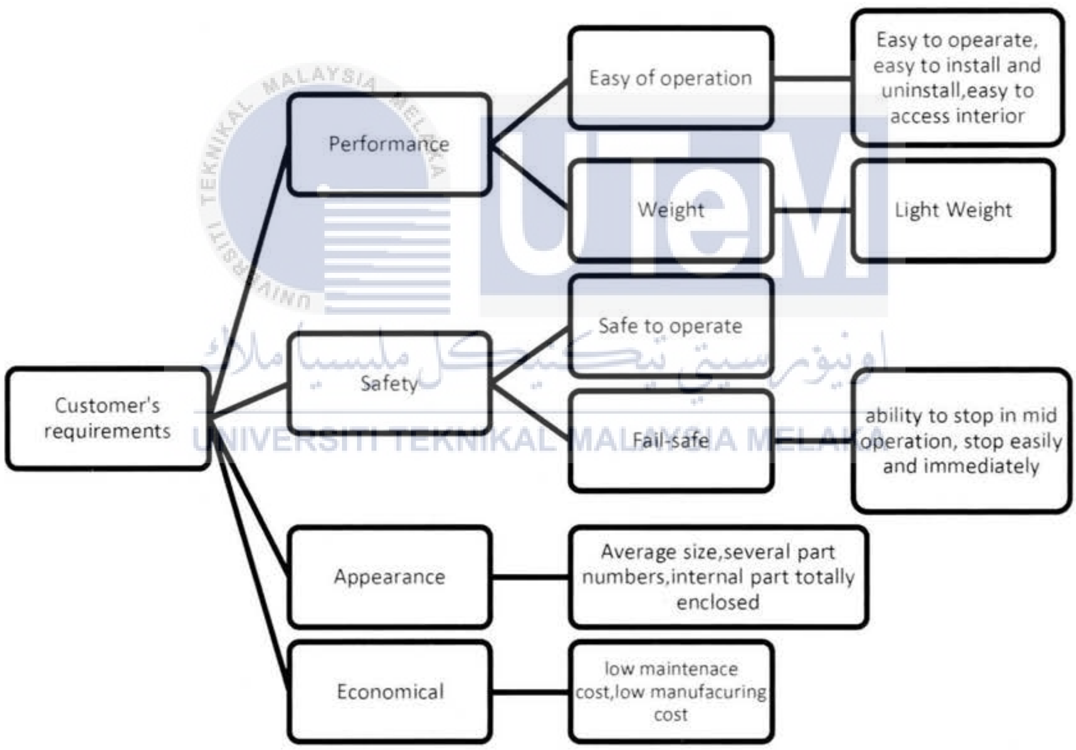


Figure 4.1: Objective tree diagram of vacuum forming machine

4.3 FUNCTIONAL STRUCTURE

After knowing the objective of the product, researchers need to convert customer's requirement into a product by function analysis. Every product has its main function and sub functions. Therefore, by doing functional analysis, they'll know there are many alternative solutions that can be generated to the proposed function. In functional analysis, we know that the main function of vacuum forming machine is to make products by thermoplastic sheets. There are 4 sub-functions in the main function of the vacuum forming machine, which is function to clamp the plastic sheet, function to heat, function to vacuum and lastly the function to press the plastic into a mould. Figure 4.2 shows the functional analysis of vacuum forming machine.

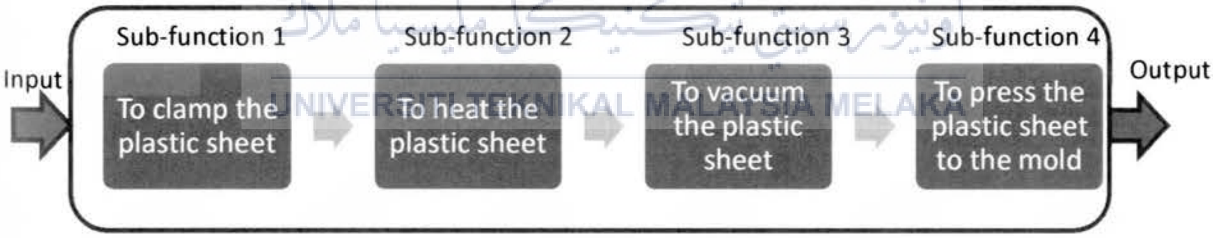


Figure 4.2: Functional analysis of vacuum forming machine.

4.4 PRODUCT DESIGN SPECIFICATION

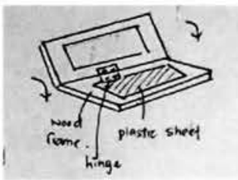
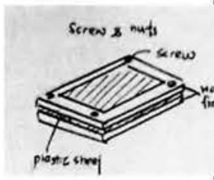
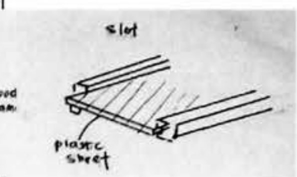
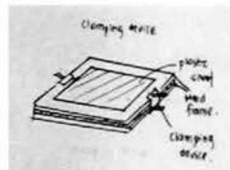
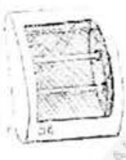
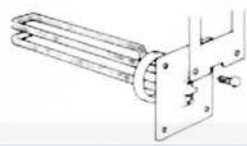
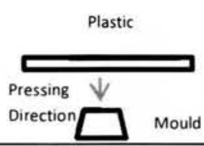
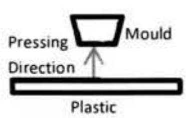
Product design specification describes what needs to be achieved in a measurable quantity rather than qualitative desire expressed at the objective stage. It will be done according to the market analysis result and objective tree diagram. At this specification stage, researchers modify the requirement's statement in more detail, in a precise limit. This stage is very important for creating a successful product. In addition, brainstorming method can be used to generate the suitable engineering specification for the product. Table 4.2 shows the product design specification of vacuum forming machine.

Table 4.2: Product design specification of vacuum forming machine

No	Criterion	Specification
1	Performance	-Weight: below 40kg -Steps to operate: less than 5
2	Safety	Safety factor of material>2
3	Appearance	Number of functional part: equal and less than 15 -Maximum height 2.0m -Maximum width 1.0m -Maximum length 1.0 m -Internal part enclosed: 100%
4	Economical	-Manufacturing cost: less than RM1000 -Maintenance cost: less than RM 500 per year

4.5 MORPHOLOGICAL CHART

Table 4.3: Morphological Chart of vacuum forming machine

Criteria	Option 1	Option 2	Option 3	Option 4
Clamping method	Hinge/Magnet 	Screw and nuts 	Rib and slot 	Clamp 
Heating Source	Heater 	Infra lamp 	Heating rod/coil 	
Vacuum pocket	Hole 	Line 		
Pressing Mechanism	From top to bottom 	From bottom to top 	From side to side 	

4.6 CONCEPTUAL DESIGN

Conceptual design is a preliminary drawing showing ideas that have been formulated after gaining some information from the customer. Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6 show the design concept of vacuum forming machine generated by using Morphological chart.

i. Design Concept 1

Clamping method: Option 1

Heating Source: Option 1

Vacuum pocket: Option 1

Pressing Mechanism: Option 3

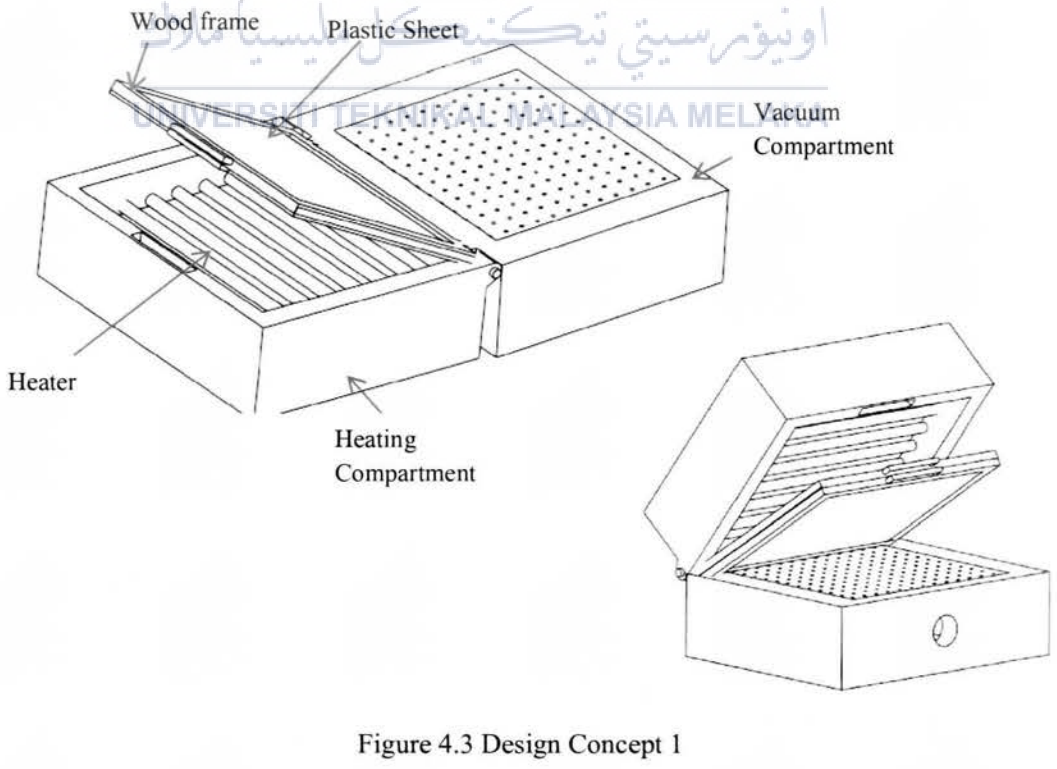


Figure 4.3 Design Concept 1

Figure 4.3 shows the design concept 1 of the vacuum forming machine, there are 2 compartments in series in this design, which are heating compartment and vacuum compartment. The heating source of this design is a heater. It will be placed inside the heating compartment which is wrapped with Aluminum foils. The function of the aluminum foils is to prevent the heat escaping from the heating compartment. Besides that, the hose of the vacuum cleaner will be connected to the hole of the vacuum compartment in order to remove air from the vacuum compartment .The plastic sheet is secured tightly in the middle of the 2 wood frames because the magnet is fit on the inner surface of the wood frame. Before conducting the vacuum forming process, the wood frame (with plastic in it) will rest on the top of the heating compartment in order to soften the plastic. When the plastic is softened, the wood frame will be moved from the heating compartment and then press against the mould which is above the vacuum compartment. The plastic will be conformed to the shape of the mould with the aid of vacuum. This design is foldable .It can be closed when not in use in order to save space.

i. Design Concept 2

Clamping method: Option 2

Heating Source: Option 3

Vacuum pocket: Option 2

Pressing Mechanism: Option 1

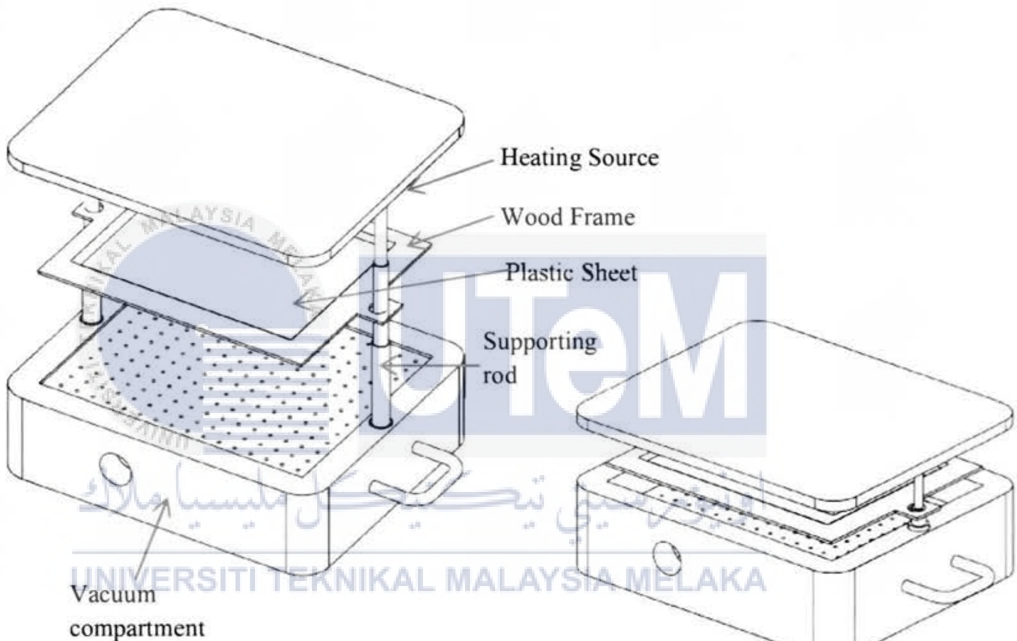


Figure 4.4 Design Concept 2

Figure 4.4 shows the design concept 2 of the vacuum forming machine. The heating source of this design is the heating coil. This plastic sheet is located in the middle of the 2 wood frames and secured by screws and nuts. The distance can be adjusted manually by moving the wood frame up and down. This feature between the heating source and the plastic sheet is very important because the heat transfer in this design is fixed. A longer distance between the heating source and the plastic sheet is suitable for a plastic sheet with low melting point in order to prevent plastic overheat.

Besides that, the supporting rod can be extended upward when in use, retracted downward when not in use.

ii. Design Concept 3

Clamping method: Option 3

Heating Source: Option 2

Vacuum pocket: Option 1

Pressing Mechanism: Option 1

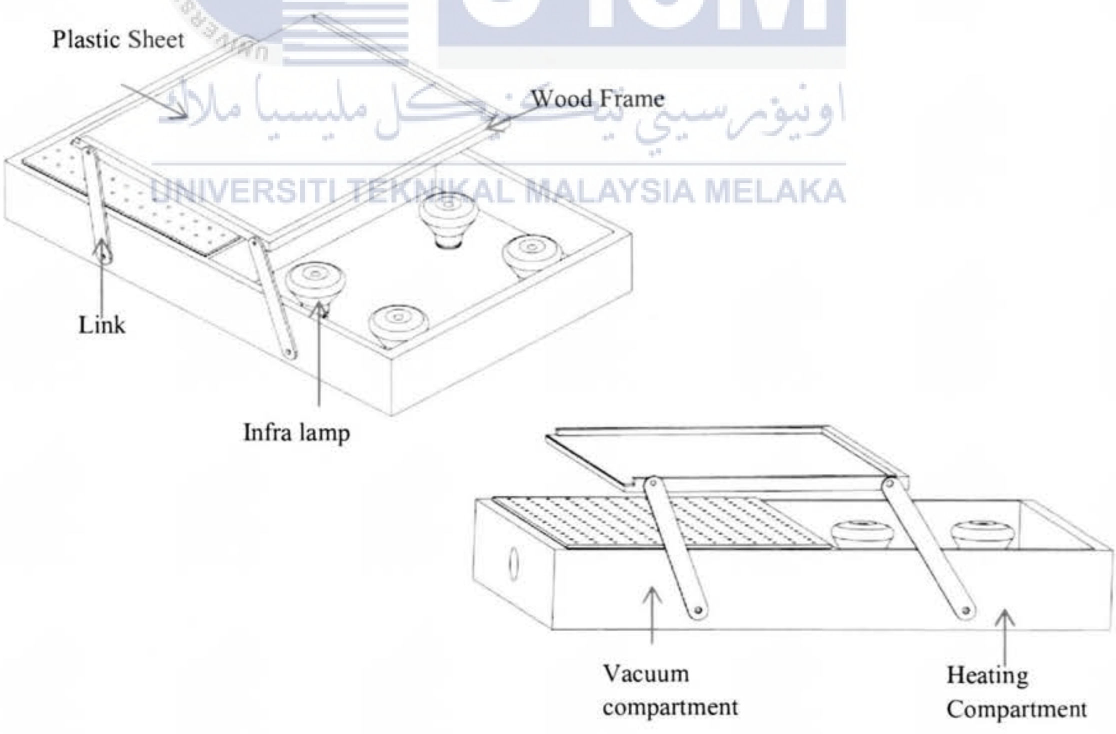


Figure 4.5 Design Concept 3

Figure 4.5 shows the design concept 3 of the vacuum forming machine. Same as the design 1, there are also 2 compartments in this design, which are heating compartment and vacuum compartment. However, the heating source of this design is infra lamp and the plastic sheet is secured in the wood frame by using slot method. Four links will be used to connect plastic sheet and the heating and vacuum compartments. When the links are rotated anticlockwise, the plastic sheet will be moved from heating source to vacuum site and vice versa. However, unlike previous design, this design is not foldable.

iii. Design Concept 4

Clamping method: Option 3

Heating Source: Option 3

Vacuum pocket: Option 1

Pressing Mechanism: Option 1

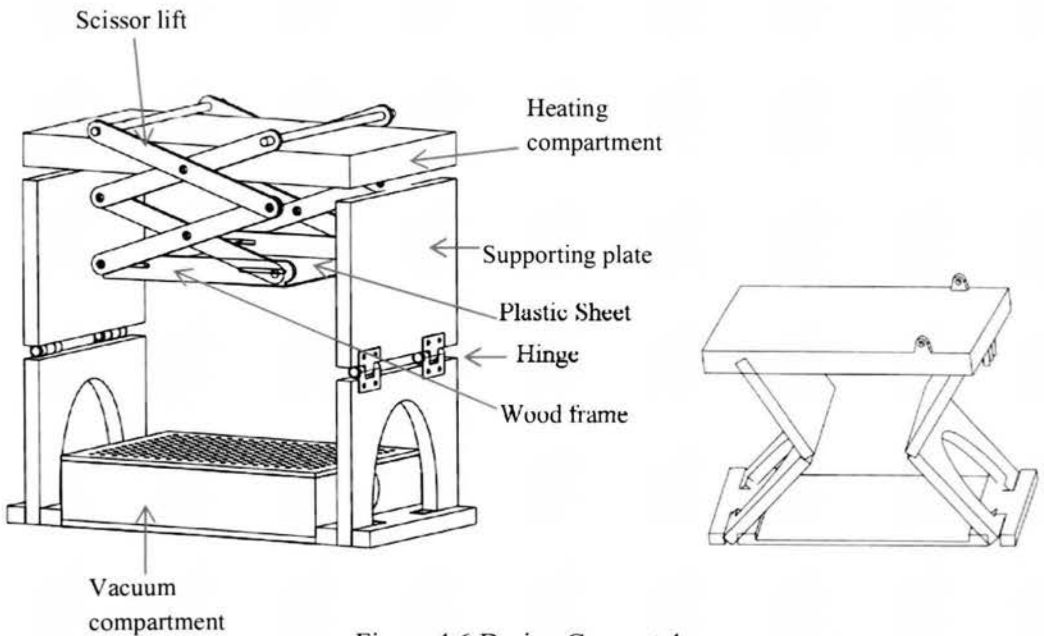


Figure 4.6 Design Concept 4

Figure 4.6 shows the design concept 4 of the vacuum forming machine. The heating source of this design is the heating coil. The plastic sheet is secured in the wood frame by using slot method .The distance can be adjusted manually by using the scissor lift. This feature between the heating source and the plastic sheet is very important because the heat transfer in this design is fixed. A longer distance between the heating source and the plastic sheet is suitable for a plastic sheet with low melting point in order to prevent plastic overheat. Besides that, the supporting plate can be folded after the vacuum compartment and scissor lifter are taken out in order to save space and easy to carry. It is multipurpose because it can be treated as a vacuum forming machine or a shelve.

4.7 COMPARISON BETWEEN 4 DESIGN CONCEPTS

In order to select the best design concept, the details of every design concept are tabulated in a table. The important parameters to be compared are performance, appearance and economical. Table 4.4 shows the comparison between the characteristic of four design concepts

Table 4.4: Comparison between the characteristic of four design concepts

No	Characteristic			Design 1	Design 2	Design 3	Design 4
1	Performance	Weight estimation in CATIA(kg)		38.10	37.15	27.29	11.54
		Steps to operate		6	6	4	4
3	Appearance	No of part		7	9	8	11
		Envelop Dimension LxMxH(m)		1.0x0.6x0.15	0.6x0.5x0.70	0.845x0.530x0.12	0.50x0.25x0.48
		Volume (m^3)		0.059	0.031	0.023	0.011
		Internal Part enclosed		Yes	Yes	Yes	Yes
4	Economical	Level of Maintenance's and Manufacturing cost	Based on no of part	low	moderate	moderate	moderate
			Based on complicity of design	moderate	high	low	high

4.8 DISCUSSION ON CHARACTERISTIC OF DESIGNS

i. Weight

The weight of vacuum forming machine is estimated roughly according to the information from the CATIA software. The weight of the design 4 is the smallest compared to other design which is only11.54kg .Design 1 has the highest weight, which 38.10kg because the wall of heating and vacuum compartment is thicker than others.

ii. Step to operate

Design 4 and Design 3 has only 4 simple steps to operate the vacuum forming machine, whereas other design has more than 4. In design 4 and 3, 1^{st}, insert the plastic sheet by slotting method. 2^{nd}, heat the plastic sheet, 3^{rd}, press the heated plastic sheet onto the mold, 4^{th} ,remove the plastic product from frame. The securing method of both design is slotting method, therefore it is easy to install and uninstall the machine. Unlike the other design, , for example Design 2, it uses screw and nuts as securing method, it is unwise because it'll take some time to do the alignment before securing the plastic sheet.

iii. Factor of Safety

All design will be designed using factor of safety more than 2 to ensure high durability of product and safe for users.

iv. No of parts

Design 4 has the highest amount of functional part which is 11 parts compare to other design. This is due to the complicity of the design using scissor life mechanism. However, design 1 has the lowest number of functional part, which is only 7 parts. This is because it doesn't need supporting rod or link to transport plastic sheet from heating compartment to vacuum compartment. The wood frame can serve that purpose other than just securing the plastic sheet.

v. Envelop Dimension and Volume of machine

The envelop dimension of all design have fulfill the customer requirement, which is lower than the maximum height 2.0m, maximum width 1.0m and maximum length 1.0 m. The volume of machine can also be estimated roughly by referring the mechanical properties of product in CATIA. From the results, it was known that Design 4 has smallest envelop dimension and volume when compare to other designs.

vi. Internal Part enclosed

The internal part of the heating compartment for all design is enclosed, in order to reduce the injury to operator especially children operator.

vii. Manufacturing cost

Design 2 and 4 can be folded when not in use in order to save space, thus they have highest manufacturing cost due to the complicity of design. On the other side, Design 3 requires the lowest manufacturing cost due to simplicity of design. It is made up of wooden box with 2 compartments; wood frame is connected to the body by four links.

4.9 CONCEPT EVALUATION AND SELECTION

Previously 4 Design concepts are generated to fulfill customer's requirement. Now, in order to select the best one, Decision matrix is used. In this method, all Design concepts will be listed in specification table. A design concept will be chosen become the datum against other concept. Therefore design 2 is chosen as datum because it seems like an obvious solution to the problem. In comparison, a concept will be given a positive score if it is better than datum whereas it will be given negative score if it is worse than datum. If the concept is same like datum, then zero will be given. A design will be selected as the best concept when its total score is highest among the others. The detail procedure of using decision matrix is shown in section 3.2.4.2. All the ranking are based on designer perception. Table 4.5 shows the Decision matrix of vacuum forming machine

Table 4.5: Decision matrix of vacuum forming machine

No	Characteristic		Weight (0-5)	Design 1	**Design 2**	Design 3	Design 4
1	Performance	Weight	3	-		+	+
		Steps to operate	3	0		+	+
3	Appearance	No of part	2	+	**D**	+	-
		Envelop Dimension	3	-		-	+
		Volume	3	-	**A**	-	+
		Internal Part enclosed	4	0		0	0
4	Economical	Maintenance's cost	4	+	**T**	0	0
		Manufacturing's cost	5	+		+	0
			Total +	3	**U**	4	4
			Total -	3		2	1
			Total s	2		2	3
			Overall Score	0	**M**	2	3
			Weighted Overall Score	2		7	10

From the result, the negative score indicate that the design is worse than the datum whereas positive score indicates that the design is better than the datum. Thus, it is observable that the design 4 has high score of specification among the others .In conclusion, Design concept 4 is selected because it is the best design among the others.

CHAPTER 5

DETAIL DESIGN

5.1 INTRODUCTION

Detail design is the phase where the design is refined, specification and estimation are created. It is a final step to be carried out before the product is manufactured and tested. In this phase, detail design skill is needed to estimate the requirement of the product in a reasonable way and refine the product to ensure the plan under cost estimation. It is a very important step because it ensures the overall design solution satisfies the project objective.

In product development process, after the best conceptual design is chosen, the researcher will design their product in more detail way which includes types of materials used for the product, manufacturing cost, manufacturing process and the geometric dimension of the product. In addition, suitable factor of safety will also be applied by the designer in order to design a zero failure product which fulfill the minimum requirement of the product. All of the criteria above will affect the performance and the safety of the final product

5.2 CATIA DRAWING OF VACUUM FORMING MACHINE

In this project, the vacuum forming machine is drawn by using CATIA V5R20. The assembly of both designs are displayed in forms of assembly view and exploded view. Apart from that, the detailed drawings are also provided in this project. All the drawings will be appended in the Appendix at the end of the final report. Figure 5.1 and Figure 5.2 shows the Assembly view and Exploded view of vacuum forming machine. Table 5.2 shows the Bill of Materials of the Vacuum Forming Machine. Details drawing of all parts are appended in **Appendix G.**

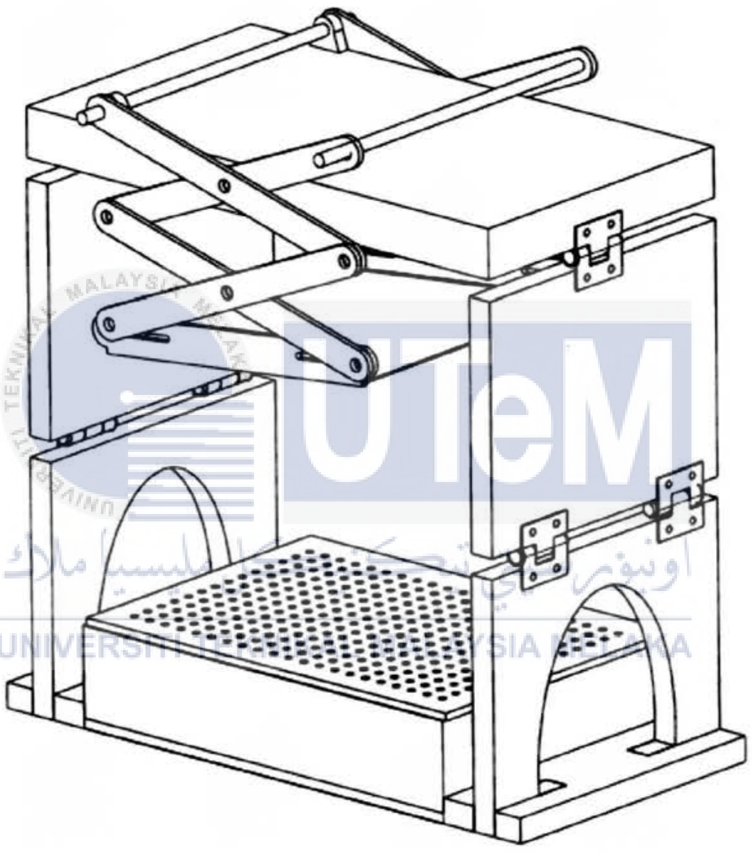


Figure 5.1 Assembly View of Vacuum Forming Machine

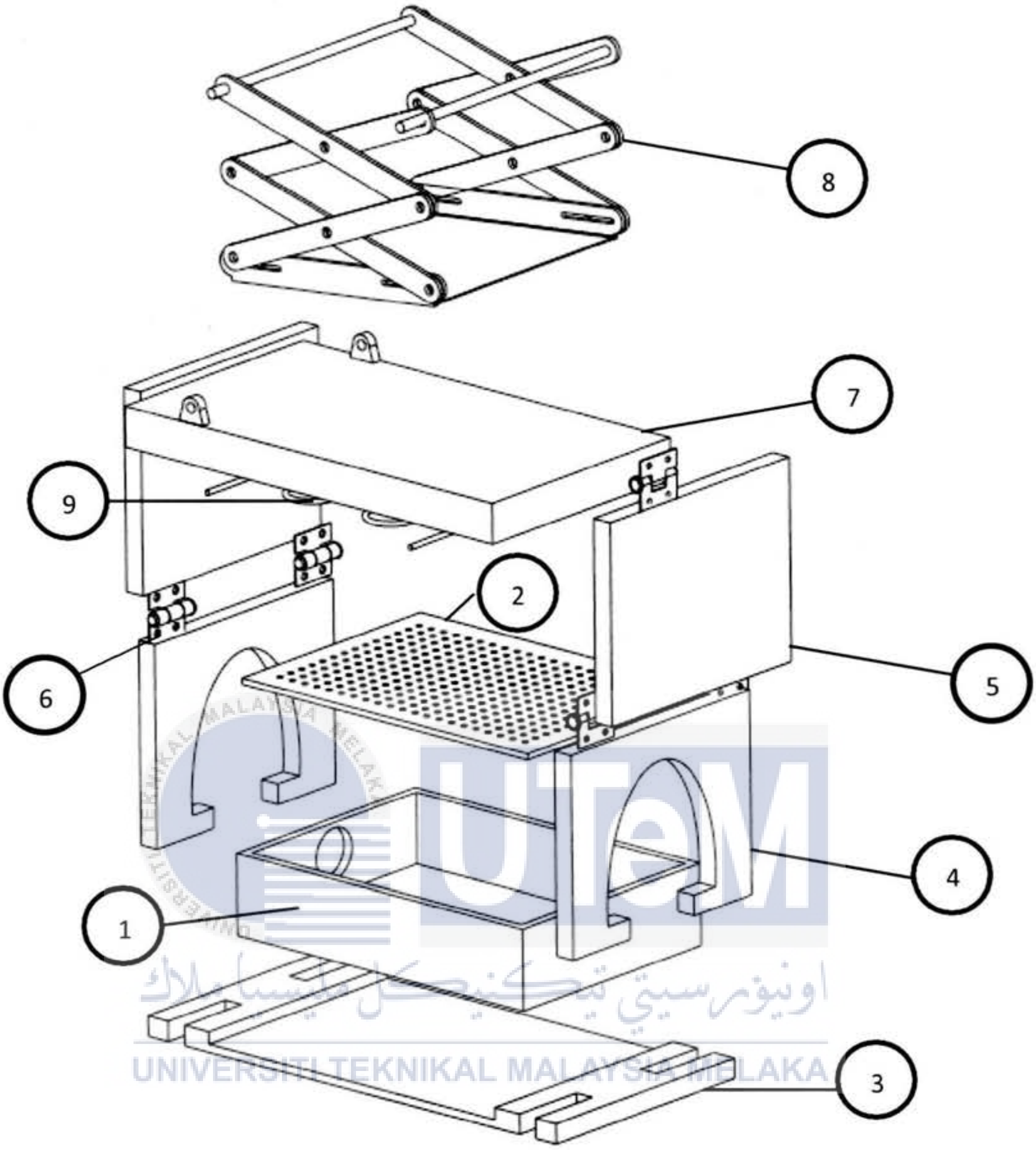


Figure 5.2 Exploded View of Vacuum Forming Machine

Table 5.1: Bill of Material of Vacuum forming machine

Part Number	Part Name	Description(s)/Function(s)	Quantity	Materials
1	Vacuum Box	• To draw the trapped air between plastic sheet and mould. • To conform the plastic	1	Plywood
2	Hole Plate	• A place to rest the mould. • Air is drawn through the hole	1	Plywood
3	Base	• To fix the Vacuum Box and Bottom Supports in place	1	Plywood
4	Bottom Support	• To provide support to the machine	2	Plywood
5	Upper Support	• To provide support to the machine	2	Plywood
6	Hinge	• To connect Upper and Bottom Supports	5	Stainless steel
7	Cover Plate	• To hold the Scissor lift in place.	1	Plywood
8	Scissor Lift	• To move up and move down the plastic sheet	1	Plywood (Stick), Stainless Steel (Connectors)
9	Heating Element	• To soften the plastic sheet	1	Nichrome Wire

5.3 COST ESTIMATION OF PROTOTYPE

Table 5.2: Cost Estimation of Prototype

No	Materials	Unit Price (RM)	Quantity/ Unit	Total Price (RM)	Remarks
1.	PlyWood	10 /meter	2 meter	20	Thickness 6mm for structure and 2.5mm for scissor lift
2.	Fine Steel Wire	3 / roll	1 roll	3	-
3.	Screw and nuts	0.5/package	2 package	1	-
4.	Hinge	0.5/unit	6 unit	3	Small size
5.	Nichrome Wire Ni80	37 /roll	1 roll	37	-
6.	Soldering Wire	12/roll	1 roll	12	-
7.	Mika resisting paper	16.8/roll	1 roll	-	Taken from broken appliance
8.	Power supply (Adapter)	60/unit	1 unit	-	Use Useless adapter
9.	Wire with clip	1/unit	2 unit	2	-
10.	Connectors	5.9/package	2 package	11.8	-
11.	Plastic Vacuum Box	2/box	1	2	-
12.	Aluminium Foil	15.09/roll	1	15.09	-
13.	Heater box	2/box	1	2	-
Total				108.89	

CHAPTER 6

PRODUCT ANALYSIS

6.1 DESIGN OF HEATING SOURCE IN VACUUM FORMING MACHINE

i. Determine the appropriate heat need to be provided by heater in order to soften plastic sheet with 0.0050m thickness in 3 min as shown in Figure 6.1.

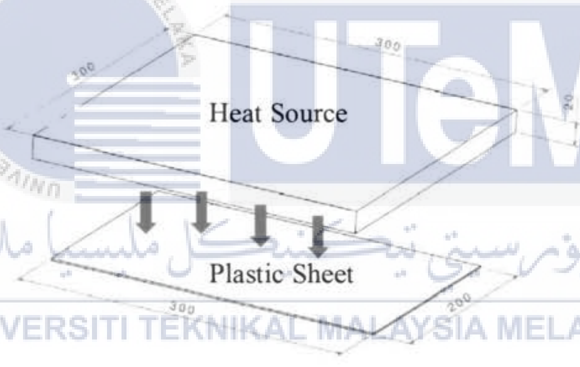


Figure 6.1: Heating Source and Plastic Sheet

Before perform the heat transfer analysis, there are several assumptions that need to be made.

Assumption

1. The heat transfer process is in steady condition.
2. The surrounding air is an ideal gas with constant properties.
3. The atmospheric pressure is 1 atm.
4. Natural convection heat transfer ,conduction and radiation will be taken into consideration because no external air applied in this case

5. The heat transfer is in one dimension, which is from bottom of heater.
6. The initial temperature of surrounding air T_{∞}, is 25 °Cand the maximum surface temperature generated by the heater T_s, is 150 °C.
7. The emissivity of the heater is 0.8.
8. The heat loss from heater to plastic sheet is negligible.

<u>Properties of Air</u>

Average temperature of air,

$$T_{ave} = \frac{T_s + T_{\infty}}{2}$$

$$T_{ave} = \frac{150+25}{2}$$

$$T_{ave} = 87.5°C$$

Then, the properties of air at 1atm can be determined by referring Table A-15 as appended in Appendix C.

$$Density, \rho = 0.9787 \frac{kg}{m^3}$$

$$\text{Specific Heat}, C_p = 1008\, J/kg.K$$

$$\text{Thermal conductivity, k} = 0.03006\text{W/m. k}$$

$$\text{Kinematic Viscosity}, \nu = 2.175\text{x}10^{-5} m^2/s$$

$$\text{Prandtl number, Pr} = 0.7138$$

<u>Properties of Heater and Plastic Sheet</u>

$$Dimension\ of\ Heater (LxWxH) = \ 0.3m\ x0.3m\ x0.02m$$

$$Dimension\ of\ Plastic\ sheet\ (LxWxH) = \ 0.3m\ x0.2mx\ 0.005m$$

$$Plastic\ Material\ = ABS$$

$$Surface\ area\ of\ heater\ A_s(bottom\ area) = 0.3mx0.3m\ = 0.09m^2$$

$$\text{Perimeter of heater}\ (bottom\ area) = 0.3mx4\ = 1.2m$$

$$Distance\ between\ heater\ and\ plastic = 0.04m$$

<u>Material Properties of ABS is appended in Appendix A.</u>

$$Specify\ Heat\ capacity\ of\ ABS, Cp =\ 1386\ J/kg.K$$

$$Density\ of\ ABS\ plastic = 1010\ kg/m3$$

$$Glass\ Transition\ Temperature\ of\ ABS =\ 87.85°\mathrm{C}$$

$$Thermal\ Conductivity = 0.188W/m.k$$

Note :All the equations used in the product analysis are taken form the book ,Heat and Mass Transfer Fundamentals and Applications.

<u>Analysis</u>

The heat conduction can be calculated by using Eq. (6.1) &Eq. (6.2) taken from Eq. (3.4) & Eq. (3.5) Page 144

$$\dot{Q_{cond}} = \frac{T_1-T_2}{R_T} \tag{6.1}$$

$$where\ R_T = R_{air} + R_{plastic}$$

$$R_T = \frac{L_a}{k_a A_a} + \frac{L_p}{k_p A_p} \tag{6.2}$$

$$R_T = \frac{0.04}{0.03006(0.3x0.3)} + \frac{0.005}{0.188(0.3x0.2)}$$

$$R_T = 0.334 + 0.443$$

$$R_T = 0.77K/W$$

Value of Eq.(6.2) is substituted to Eq.(6.1) to get Eq.(6.3)

$$\dot{Q_{cond}} = \frac{T_1 - T_2}{R_T} \tag{6.3}$$

$$\dot{Q_{cond}} = \frac{150 - 87.85}{0.77}$$

$$\dot{Q_{cond}} = 79.96W$$

The radiation heat can be calculated by using Eq. (6.4) taken from Eq. (1.28) Page 29.

$$\dot{Q_{rad}} = \epsilon A_s \sigma ({T_s}^4 - {T_\infty}^4) \tag{6.4}$$

$$\dot{Q_{rad}} = 0.8x0.09x5.67x10^{-8}[(150 + 273)^4 - (25 + 273)^4]$$

$$\dot{Q_{rad}} = 98.50\text{W}$$

Thus, the total rate of heat transfer of heater can be calculated by using Eq.(6.5), which is taken from Eq. (1.29) Page 29

$$\dot{Q_T} = \dot{Q_{cond}} + \dot{Q_{rad}} \tag{6.5}$$

$$\dot{Q_T} = 79.96 + 98.95$$

$$\dot{Q_T} = 178.91W$$

The amount of heat transfer needed to raise the temperature of the ABS to its glass transition temperature in 3min can be calculated by using Eq. (6.6) taken from Eq. (1.18) Page 13

$$Q = mc_p(T_2 - T_1) \tag{6.6}$$

$$Q = mx1386\text{x}(87.85 - 25)$$

$$Q = 87110.1mJ \tag{6.7}$$

Then, the mass of plastic sheet can be determined by substituting Eq. (6.5) and Eq. (6.7) to Eq. (6.8) taken from Eq. (1.7) Page 9

$$\dot{Q}_T = \frac{Q}{t} \tag{6.8}$$

$$\dot{Q}_T = \frac{87110.1(0.09)}{3x60}$$

$$\dot{Q}_T = 43.55W$$

Thus, 0.005m thickness of ABS plastic sheet can be soften and formed after being heated at around 44 W for 3 min. From the calculation, the heat provided by the heater is more than the required heat. Therefore, the heater provides sufficient heat to soften the plastic.

ii. Cooling of a ABS Plastic in a Mold

By assuming that a ABS plastic of 5 mm thickness initially at 87.85°C is cooled in a mold and the mold surface is at 30°C. The time taken for the temperature to reach 40°C at the midplane (x_m= 5/2 = 2.5 mm) will be calculated

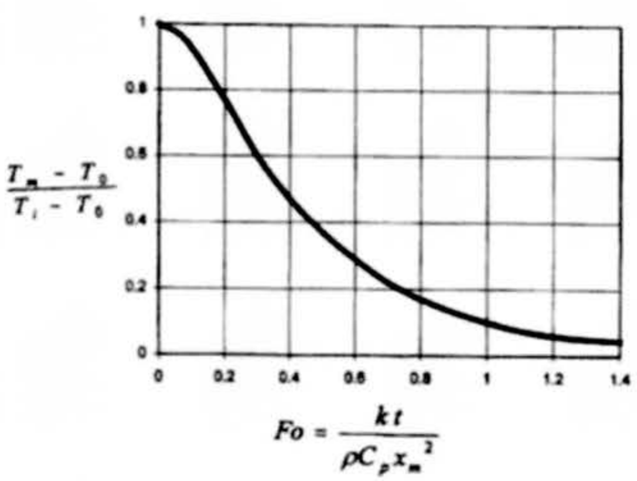


Figure 6.2 : Heisler Chart

Fig 6.2 will be used for Ti = 87.85°C, T0 = 30°C, and Tm = 40°C. The vertical axis of Fig 6.2 is calculated as follows

$$\frac{T_m - T_o}{T_i - T_o} = \frac{40 - 30}{87.85 - 30} = 0.1728 \tag{6.9}$$

The corresponding Fourier Number is

$$F_o = \frac{kt}{\rho C_p {x_m}^2} = 0.8 \tag{6.10}$$

Using typical thermal properties for ABS as shown in previous,

$$\frac{0.188t}{1010(1386)(0.0025)^2} = 0.8$$

$$t = 37.23s$$

Therefore, it was known that 37.23s needed to cool a 5mm ABS plastic in a Mold.

6.2 DESIGN OF HEATING ELEMENT IN PROTOTYPE DEVELOPMENT

i. Determine the length of Nichrome wire needed to use as heating element.

<u>Experimental Setting(Fixed Variable)</u>

Number of Wire Gauge: 24 gage

Type of Power Supply: AC to DC adapter

Input: 100V~240V, 1.5A ;Output :19V, 4.74A,

Resistance of Nichrome wire per meter: 6.2 ohm/meter

In order to create a safe heating source, the suitable length of the nichrome wire need to be considered. Nichrome wire is a resistor in the circuit, when the electricity pass through it, it will turn electrical energy to heat energy. It is common heating element used in electrical appliances due to its high melting point, which can withstand up to thousand celcuis. Therefore, in order to create a heating source, the power supply must equal or larger than the power needed by the circuit. This is because improper setting of circuit will cause the power inefficiency and the occurrence of electricity cut off. One twice as large would provide a good safety factor and keep from burning up the power supply.

According to Eq. (6.11), the relationship between voltages is directly proportional to current and resistance. Figure 6.3 shows the basic circuit of heater, where the V and I represent the Voltage and Current of adapter power source; whereas R represents the Resistance of Nicrhrome wire.

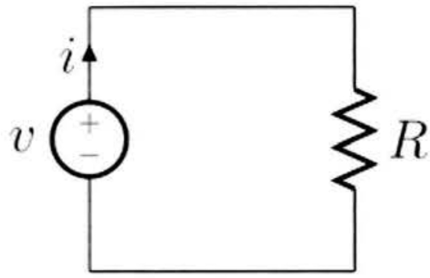


Figure 6.3 : Circuit of heater

$$V = IR \tag{6.11}$$

$$19 = 4.74R$$

$$R = 4\ Ohm$$

$$Required\ Length\ of\ Nichrome\ wire$$

$$L = \frac{4\ ohm}{6.2\ \text{ohm/meter}}$$

$$L = 0.66 meter$$

Therefore, the length of Nichrome wire must equal or larger than 0.66m in order to run the heater safety.

According to the table of current temperature provided by JacobsOnline.com (Anon., The temperature of heat generated by the 24 gauge nichrome wire, which subjected to 4.74 A ,is around 600 degree celcuis.

The power produce by the power source in prototype can be calculated by using Eq. (6.13).

$$P = VI \tag{6.13}$$

$$P = 19X4.74$$

$$P = 90.06W$$

CHAPTER 7

PROTOTYPE MANUFACTURING AND TESTING

7.1 APPARATUS AND MATERIALS

i. Plywood

Plywood is a multipurpose construction material that is made from thin layers. Several thin layers of wood are glued together to form a strong wood structure with light weight. It is always a best choice for researchers/hobbyists in selecting prototype materials since it is a very durable material that provides an excellent foundation for building. Besides that, plywood is relative cheap when compared to other type of wood boards, which makes it an ideal building material for making DIY projects.

Figure 7.1: Plywood

ii. Stainless Steel Connectors

Stainless steel is iron alloy with a minimum of 10.5% chromium. Other metals such as Nickel, Copper, Titanium and others can be added to enhance the metal structure and properties such as formability, strength and toughness. Stainless steel is a type of steel that has ability to resist stains and corrosion. In the prototype-making-process, the connectors such as screw, hinge, bolts and nuts which are made up of stainless steel, will be chosen as the supporting joint in the vacuum forming machine. This is because they has high ductility, strength and hardness. Figure 7.2 shows the stainless steel hinge

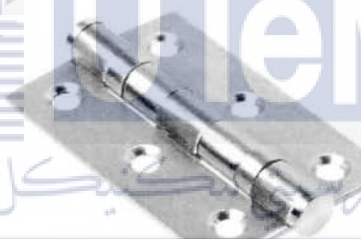


Figure 7.2: Stainless steel hinge

iii. Nichrome Wire

Nichrome wire is wire which is made of an alloy of nickel, chromium and often irons. The most common use of Nichrome is used as a resistance wire or heating element in electrical appliances such as bread toaster, iron, hair dryer and etcetera. It is suitable to be used as heating element because it has high electrical resistance, high melting point and high resistance to high temperature oxidation. The properties of nichrome vary depending on its alloy. There are two type of Nichrome wire , which are Type A and Type C Nichrome wire. Table 7.1 shows the comparison between different type of nichrome wire. Figure 7.3 shows type A nichrome wire with 24 gage

Figure 7.3: Type A Nichrome wire with 24gage

Table 7.1 : Comparison between different type of Nichrome wire

Properties	Type A	Type C
Composition	80% Nickel and 20% Chromium	60% Nickel, 16% Chromium, and the balance of 24% Iron
Maximum temperature range	1150°C	1000°C
Coefficient of resistance	Medium	High
Corrosion resistance	Excellent	Excellent
Wire gauge	0-46 gauge	0-46 gauge
Application	Most commonly used	Suitable to be used in applications where a higher resistance is required within a limited space.

iv. Steel wire

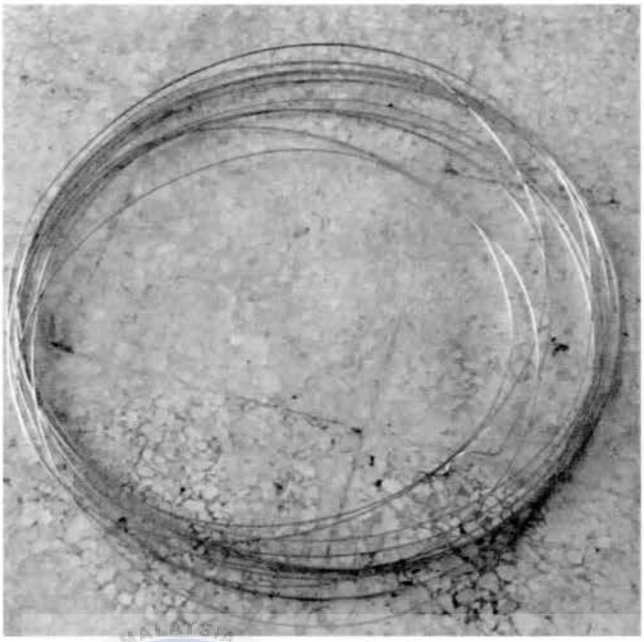


Figure 7.4: Steel wire

v. Hand drill and its drill bits

Figure 7.5: Hand drill and its drill bits

iv. Others Materials and Apparatus

Table 7.2 and Figure 7.6 show the other materials and apparatus used in prototype development.

Table 7.2 Other Materials and Apparatus

No	Materials/Apparatus
1	Aluminum Foil
2	Heavy Duty Adhesive Clay
3	Copper Wire
4	Flexible Ruler
5	Nichrome Wire
6	Test Pen
7	Screw Drivers
8	Soldering Wire
9	Connectors
10	Adhesive Tape
11	Pen
12	Ruler
13	Pliers
14	Sandpaper
15	Screws, Hinge, Bolts and Nuts
16	Blade
17	Soldering Gun
18	Handsaw

Figure 7.6 Other Materials and Apparatus

7.2 MANUFACTURING PROCESS

i. Wood Cutting

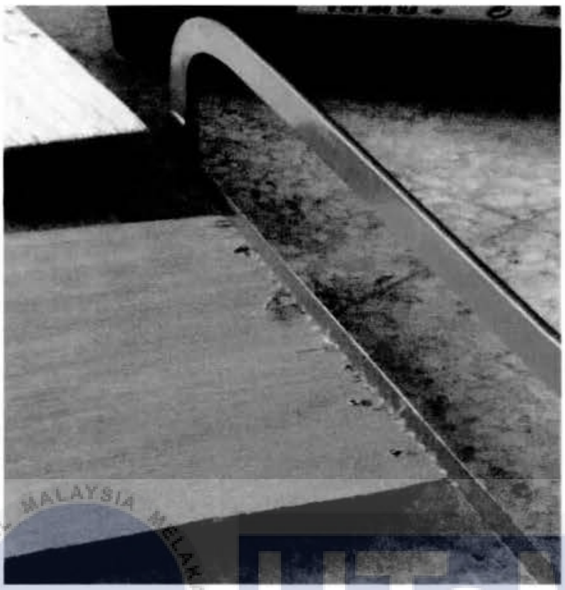


Figure 7.7 Wood Cutting

After measurement, the material will be cut into shape by using cutting tools .The proper selection of the cutting tool can control the productivity and efficiency of the wood cutting process. Besides that, appropriate cutting tool can also produce the end product with accurate dimension and good surface finishing. In the prototype-making-process, plywood will be cut into shape by using band saw.

ii. Drilling

Figure 7.8 Drilling

Drilling is a manufacturing process where a round hole is created within a work piece or enlarged by rotating an end cutting tool, a drill. The drill bit is pressed against the work piece and rotated at rates from 100-1000 revolutions per minute. In the prototype-making-process, a hand drill with different drill bits will be used to drill/create various holes in plywood, steel and PVC box

iii. Securing method (Adhesive bonding/screws)

Figure 7.9 Heavy Duty Adhesive Clay

Figure 7.10 Screwing

Figure 7.11 Hot Glue Gun

Adhesive bonding is used to fasten/secure two surfaces together without leaving a hole or pocket to the workpiece. It can produce the end product with good or smooth surface finish. The most commonly used adhesive bonding method is super-glue, that self-cure with heat has allowed adhesion with a strength approaching that of the bonded materials themselves. In the prototype-making-process, the plywood with small thickness will be joined together using hot-glue. This is because the thin plywood will be easily cracked if secure with screws or nails.

However, part with relative large thickness will be secured by using screws in order to provide firm support to the product .

iv. Soldering

Figure 7.12 Soldering PCB board of hot gun blower

Figure 7.13: Soldering PCB board of bread toaster

Soldering process is a process used to join 2 or more metals together by melting solder into the desired joint. Solder is a low melting point metal alloy used to create a permanent bond between metal workpiece. However, unlike welding process, soldering process does not involve melting the workpieces. Soldering is most commonly used in electronics and plumbing industry. In the prototype-making-process, a heater will be created by soldering the nichrome wire,copper wire and some electronic components in place.

v. Finishing(Wood Grinding)

Figure 7.14: Half round steel file

Figure 7.15: Sand Paper

Wood finishing is the last manufacturing process that provides a desirable characteristic to wood surface. The finishing process can enhance the appearance of wood surface, ease the cleaning process and decrease the injury when handling the wood. In the prototype-making-process, the plywood will be grinded properly using sand paper after the wood cutting process.

7.3 PROTOTYPE DEVELOPMENT

7.3.1 Heater Building and Testing

In 1st Trial, the Power Supply of CPU was used to make a heating source for vacuum forming machine. The power supply is put in the box to prevent the user access electrical component and get electrical shock. Besides that, Several holes are created in the box act as exhaust of the heater, to prevent overheat of electrical component in long term usage .Other than that, Indicator light is connected to the circuit in order to indicate the power is on. However, the heater did not last long after few testing. The reason of failure may due to the complicated circuit of CPU; there are many variables need to be considered during testing. The performance of heater is unstable; fuse was broken in the middle of heating. Figure 7.16 to Figure 7.18 shows the heater made up of CPU Power Supply.

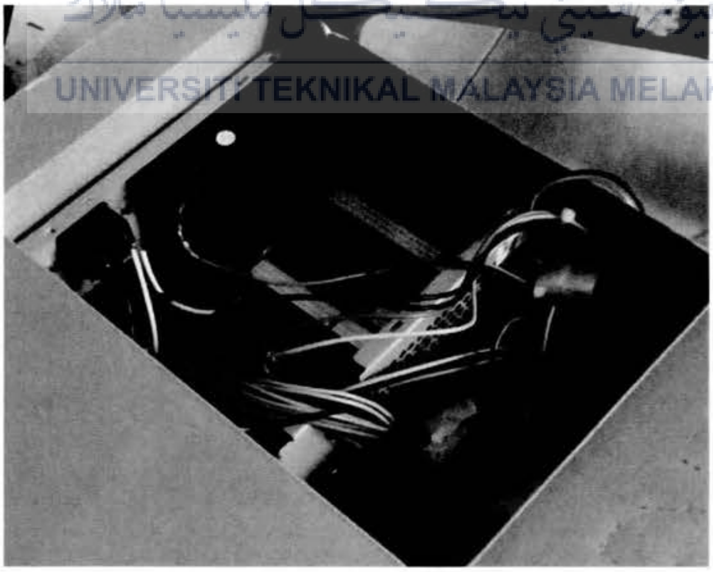


Figure 7.16: Circuit of CPU

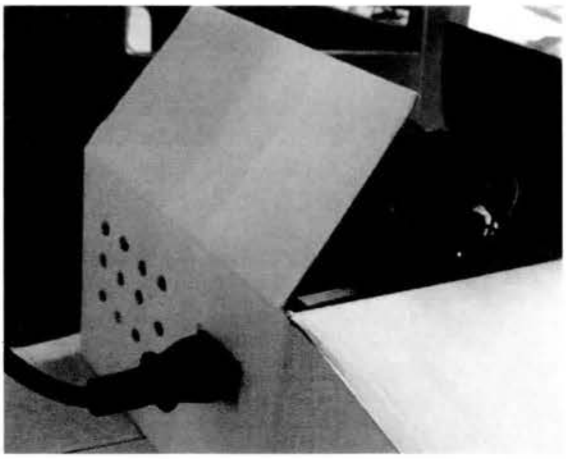


Figure 7.17: Exhaust of heater

Figure 7.18: Indicator Light

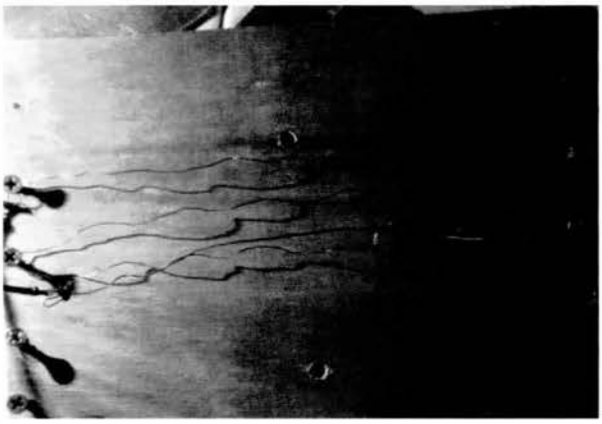


Figure 7.19: Nichrome Wire connected to the Power Supply

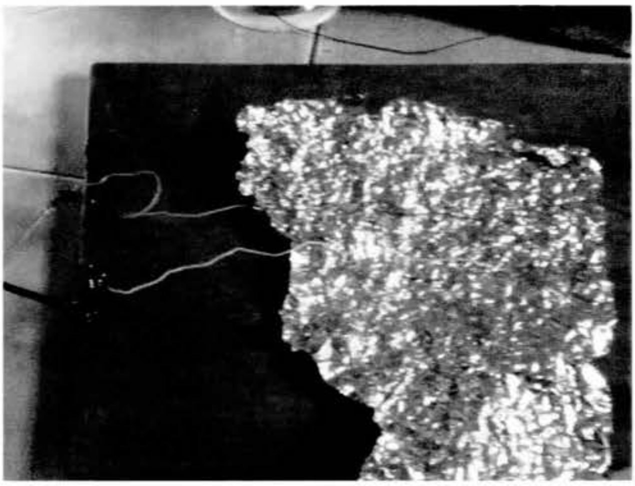


Figure 7.20: Nichrome Wire glows when connected to CPU

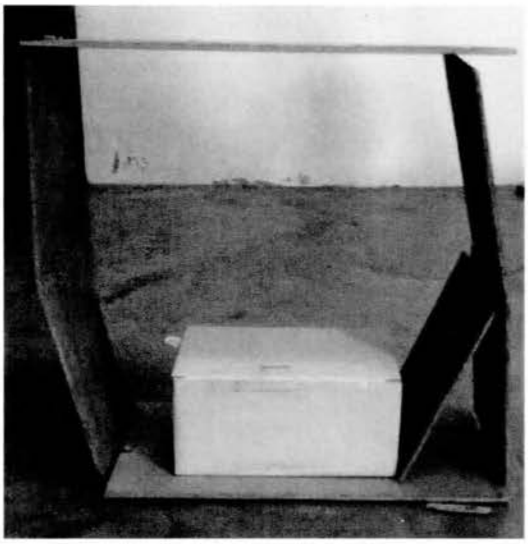
In 2nd Trial, the laptop adapter was used to make a heating source for vacuum forming machine. Its circuit is simple and easy to be manipulated when compare to the CPU. Besides that, unlike CPU circuit, it is 100% internal enclosed, which is very safe to use. Besides that, it is light and small, easy to be carried and stored. Figure 7.21 shows the laptop adapter. The two end of the wire will be connected to the Nichrome wire. Figure 7.22 shows the nichrome wire glows after connected to adapter.

Figure 7.21: Laptop Adapter with Cut End

Figure 7.22: Nichrome Wire glows when connected to Adapter

7.3.2 Structure Building

In 1^{st} Trial 1, the structure of vacuum forming machine is unstable and tends to collapse due to the foldable feature of the structure as shown in Figure 7.23. Therefore, in 2^{nd} trial ,an extra frame was slotted in behind of the structure in order to give additional support to the frame as shown in Figure 7.24 and 7.25.



F igure 7.23: Unstable Structure

Figure 7.24: Foldable Feature Structure

Figure 7.25: Adding Extra frame by slotting method

Figure 7.26: Stable Structure

7.3.3. Vacuum box building

In 1^{st} Trial, cardboard box was used as the vacuum box of vacuum forming machine. The cardboard box was seal at all ends to prevent the inefficiency during air drawing. Several hole were on top of the box made in order to draw air between the plastic sheet and the mold.. A large hole was also made on one side of the box. The vacuum cleaner hose will be inserted into the large hole to draw the air out. However, this approach was fail because the cardboard box was not strong enough to withstand the strong pressure; the cardboard dent inward and tore down immediately. In 2^{nd} trial, a thick PVC box was used instead of cardboard; it did not dent inward during air drawing because of its high strength properties. Figure 7.27 and Figure 7.28 show the vacuum box made of cardboard and PVC respectively.

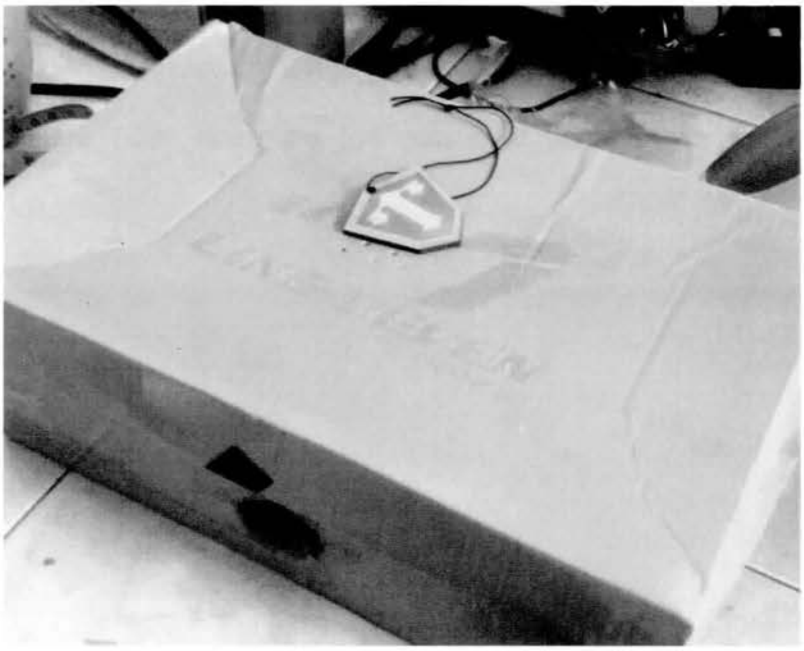


Figure 7.27: Vacuum box made of cardboard

Figure 7.28: Vacuum box made of PVC

7.3.3 Vacuum forming Machine Assembly

The vacuum forming machine was developed as shown in Figure 7.29. There are five functional parts in vacuum forming machine.

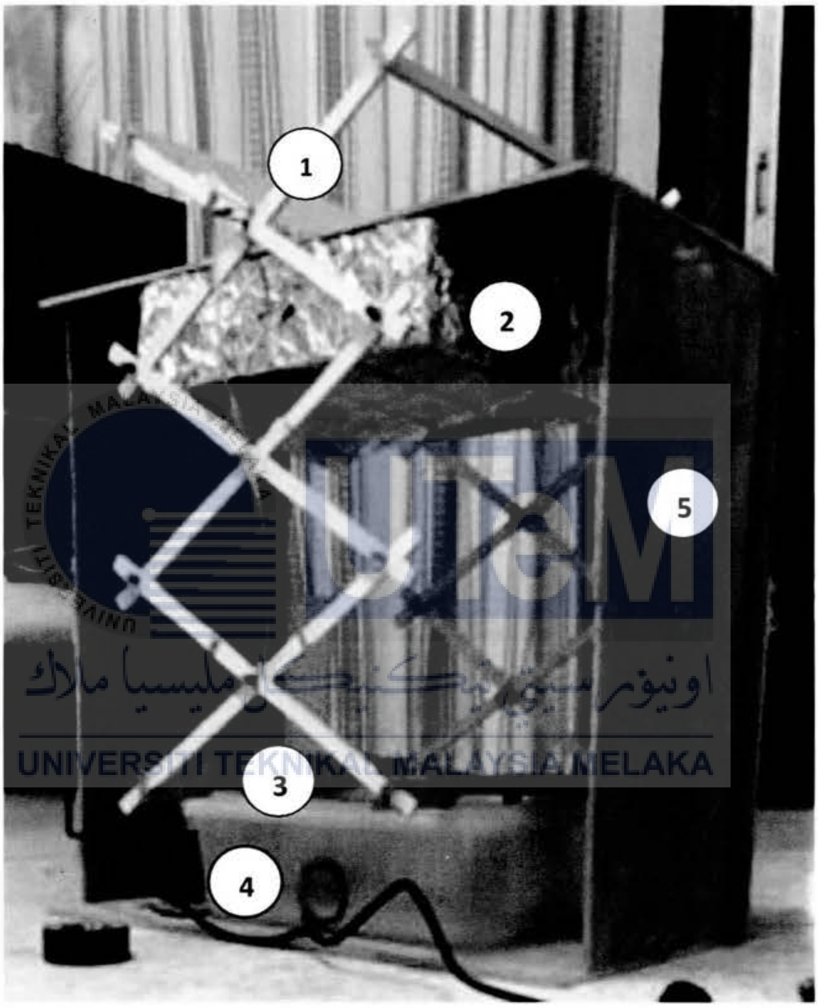


Figure 7.29: Prototype of Vacuum Forming Machine

Function of different parts of vacuum forming machine

1. Scissor lift: It acts as a tool to adjust the distance between the plastic sheet, heater and vacuum box. It lifts plastic upward for heating; it moves plastic downward for vacuum forming.

2. Heater: It is used to soften the plastic before plastic go through vacuum forming . It is made up of nichrome wire which connected to DC power supply. The nichrome wire was secured and rest on the mika resisting paper which was hang firmly in the heater box. The heater has a fixed power of 90W.
3. Plastic holder: It holds the plastic in place by using slotting method.
4. Vacuum box: It draws the excessive air out from the plastic and the mold during forming. The hole of the vacuum box will be connected to the vacuum cleaner hose.
5. Supporting Plate: It is the frame/ support of the vacuum forming machine. It is foldable, easy to carry and store.

7.3.4 Vacuum forming Process

The plastic sheet was secured in the plastic holder and then lifted up for heating as shown in Figure 7.30. However, it takes long time to heat the plastic because the heat supplied by the nichrome wire is not converging, it cannot provide sufficient heat to soften the plastic. Therefore, Aluminium foil was used as shown in Figure 7..31, to prevent the heat escape out/diverging. After few minutes, the plastic starts hanging down which indicates it become soft. Figure 7.32(a)&(b) shows the plastic hanging down. Figure 7.33 (a)&(b) shows the vacuum forming process.

Figure 7.30: Prototype of Vacuum forming machine when plastic is lift up

Figure 7..31: Vacuum forming machine wrapped with Aluminium foil.

Figure 7.32(a): Plastic hanging down.

Figure 7.32(b): Plastic hanging down.

Figure 7.33(a): Vacuum Forming Process

Figure 7.33(b): Vacuum Forming Process

7.3.5 Vacuum forming Products

In 1st trial, the vacuum forming process was not successful because the plastic haven't soft enough to conform it to mold. The plastic sheet became hard irregular shape after cooling down. Figure 7.34(a) to Figure 7.34(d) show the Product of Failure. After several trial and errors, it was known that the important factors that affect the performance of vacuum forming machine are the heating time of plastic and the speed of plastic travel from heating site to vacuum site. It was known that the heating time should be around 2-3 minutes in order to fully soften the plastic. Besides that, the distance between the heating source and vacuum site can be decreased in order to decrease the of plastic travel time. Figure 7.35 (a) to Figure 7.35(d) show successful vacuum formed product.

Figure 7.34(a): Product of Failure

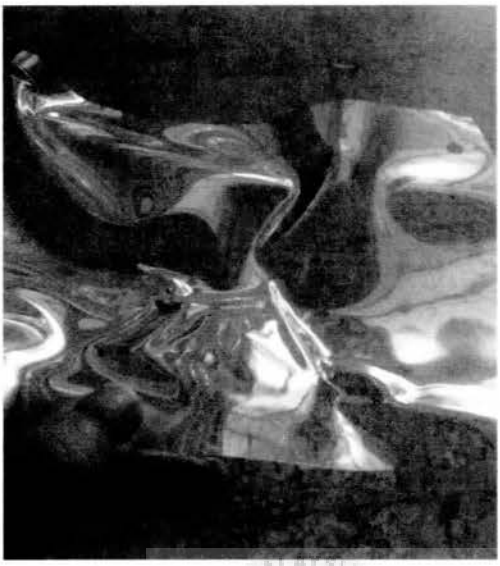


Figure 7.34(b): Product of Failure

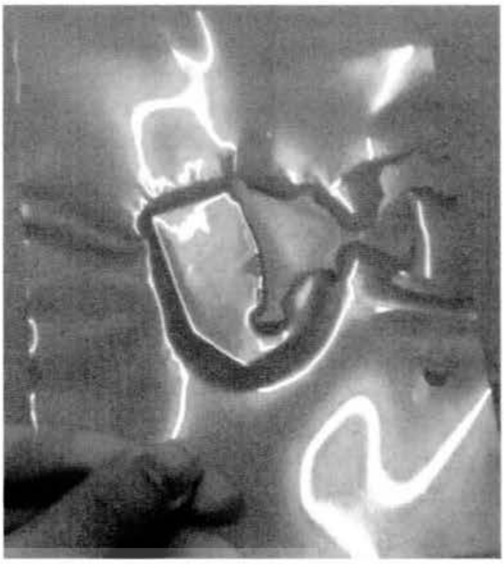


Figure 7.34(c): Product of Failure

Figure 7.34(d): Product of Failure

Figure 7.35(a): Successful product

Figure 7.35(b) Successful vacuum formed product.

Figure 7.35(c) Successful vacuum formed product.

Figure 7.35(d) Successful vacuum formed product.

CHAPTER 8

DISCUSSION ON CONSTRAINTS AND PROBLEMS IN PROTOTYPE DEVELOPEMNT

There are several limitations in prototype development. First, normal PVC plastic sheet will be used in prototype testing instead of ABS sheet. This is because a lot of plastic sheet are needed during prototype testing, therefore cheap PVC plastic is more suitable than ABS plastic sheet. Second, the power supply of heater is fixed to only 90W .The user can not adjust the power supply but the length of heating element (nichrome wire) in order to achieve the desired heating temperature. Third, it is difficult to make a strong DIY vacuum site. Therefore, the vacuum will be created by connecting the vacuum cleaner hose to the vacuum box. Besides that, there are some failures or problems occur during vacuum forming process. Initially, the researcher failed to vacuum-form the plastic due to wrong estimation of heating time. It is difficult and subjective to estimate the time when the plastic reaches its glass transition temperature. The researcher can only observe the changes of plastic shape, and assume it has reached its glass transition temperature when it is bent downward. Finally, plastic was successfully vacuum-formed after several trial and errors.

CHAPTER 9

CONCLUSION AND RECOMMENDATION

9.1 CONCLUSION

As mentioned earlier in the introduction, the purpose of this project is to design and develop a simple and low cost vacuum forming machine The purpose of this project haven been achieved through market analysis, brainstorming , software CATIA V5R20 and other engineering design methods. The developed vacuum forming machine has fulfilled the objective of the project because the machine is produced in low manufacturing cost which is only RM108.89. Besides that, product analysis were carried out in order to calculate and determine the amount of power supply required to heat the plastic sheet until it is soften. From the results, it was known that 1.5mm thickness of ABS plastic sheet can be soften and formed after being heated at around 44 W for 3 min. However, the developed prototype is not 100 percent similar to the original design. There are some limitations in prototype development. For example, this vacuum forming machine can only be operated manually. Therefore, users need to estimate the heating time and the distance by themself.

9.2 RECOMMENDATION FOR FUTURE WORK

In order to improve the design, it is recommended that in the researcher should use thermostat to control the heating temperature, so that the plastic will not be over-heated. Besides that, a timer or indicator light should be embedded in the machine in order to indicate the user when the plastic reach its glass transition temperature.

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APPENDIX A

Material Properties of Acrylonitrile butadiene styrene (ABS)

crylonitrile butadiene styrene (ABS)

e: only one typical science note is linked from this example of a CES EduPack Level 2 datasheet, laying the optional Eco and durability properties. (See also aluminium, which is displayed in the dard level 2 format without optional Eco and durability properties).

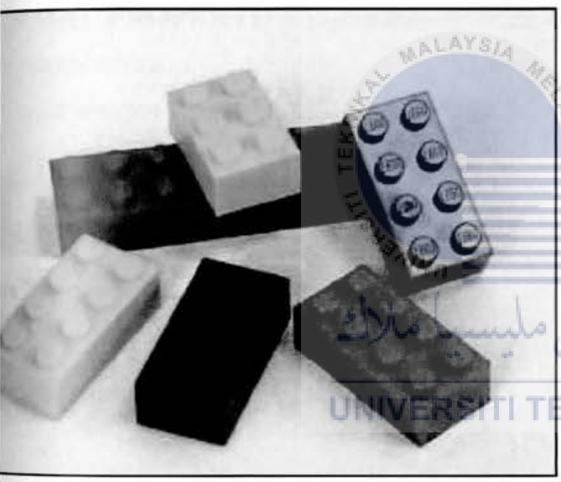
scription

E MATERIAL

S (Acrylonitrile-butadiene-styrene) is tough, resilient, and easily molded. It is usually opaque, although e grades can now be transparent, and it can be given vivid colors. ABS-PVC alloys are tougher than dard ABS and, in self-extinguishing grades, are used for the casings of power tools.

MPOSITION

ck terpolymer of acrylonitrile (15-35%), butadiene (5-30%), and Styrene (40-60%).



picture says a lot: ABS allows detailed moldings, accepts r well, and is non-toxic and tough enough to survive the st that children can do to it.

NERAL PROPERTIES

sity	1010	-	1210	kg/m^3
e	1.47	-	1.62	GPD/kg

CHANICAL PROPERTIES

ng's modulus	1.1	—	2.9	GPa
ar modulus	0.3189	—	1.032	GPa
k modulus	3.8	-	4	GPa
sson's ratio	0.3908	-	0.422	
d strength (elastic limit)	18.5	-	51	MPa

ile strength	27.6	—	55.2	MPa
pressive strength	31	-	86.2	MPa
gation	1.5	—	100	%
lness—Vickers	5.6	—	15.3	HV
gue strength at 10^7 cycles	11.04	—	22.08	MPa
ture toughness	1.186	-	4.289	MP a.m^1/2
hanical loss coefficient (tan ı)	0.01379	—	0.04464	

ERMAL PROPERTIES

s temperature	87.85	-	127.9	°C
imum service temperature	61.85	-	76.85	°C
imum service temperature	-123.2	-	73.15	°C
rmal conductor or insulator?	Good insulator			
rmal conductivity	0.188	—	0.335	W/m.°C
cific heat capacity	1386	—	1919	J/kg.°C
rmal expansion coefficient	84.6	—	234	µstrain/°C

CTRICAL PROPERTIES

trical conductor or insulator?	Good insulator			
trical Resistivity	3.3e21	-	3e22	µohm.cm
ectric constant tive permittivity)	2.8	-	3.2	
ipation factor ectric loss tangent)	3e-3	-	7e-3	
ectric strength ectric breakdown)	13.8	—	21.7	1000000 V/m

TICAL PROPERTIES

sparency		Opaque	
active Index	1.53	—	1.54

essability (scale 1=impractical to 5=excellent)

ability	1	—	2
dability	4	—	5
hinability	3	—	4
dability	5		

bility: water and aqueous solutions

er (fresh)	Excellent
er (salt)	Excellent
s, acidic (peat)	Excellent
s, alkaline (clay)	Excellent
e	Excellent

bility: acids

ic acid (10%)	Excellent
ic acid (glacial)	Unacceptable
c acid (10%)	Excellent

rochloric acid (10%)	Excellent
rochloric acid (36%)	Limited use
lofluroic acid (40%)	Limited use
ic acid (10%)	Excellent
ic acid (70%)	Unacceptable
sphoric acid (10%)	Excellent
sphoric acid (85%)	Excellent
uric acid (10%)	Excellent
uric acid (70%)	Excellent

bility: alkalis

um hydroxide (10%)	Excellent
um hydroxide (60%)	Excellent

bility: fuels, oils and solvents

l acetate	Unacceptable
zene	Unacceptable
on tetrachloride	Unacceptable
roform	Unacceptable
le oil	Excellent
el oil	Excellent
icating oil	Excellent
ffin oil (kerosene)	Excellent
l (gasoline)	Excellent
one fluids	Excellent

nene	Unacceptable
entine	Unacceptable
table oils (general)	Excellent
e spirit	Excellent

bility: alcohols, aldehydes, ketones

aldehyde	Unacceptable
one	Unacceptable
l alcohol (ethanol)	Unacceptable
lene glycol	Excellent
ıaldehyde (40%)	Excellent
erol	Excellent
ıyl alcohol (methanol)	Unacceptable

bility: halogens and gases

rine gas (dry)	Unacceptable
rine (gas)	Excellent
Oxygen gas)	Unacceptable
ır dioxide (gas)	Unacceptable

bility: built environment

strial atmosphere	Acceptable
l atmosphere	Excellent
ine atmosphere	Excellent
radiation (sunlight)	Poor

bility: flammability

nmability	Highly flammable

bility: thermal environments

rance to cryogenic peratures	Unacceptable
rance up to 150C (302 F)	Acceptable
rance up to 250C (482 F)	Unacceptable
rance up to 450C (842 F)	Unacceptable
rance up to 850C (1562 F)	Unacceptable
rance above 850C (1562 F)	Unacceptable

-economic data for principal component

ıal world production	*5.6e6	-	5.7e6	tonne/yr

rves	* 1.48e8	-	1.5e8	tonne

ary material production: energy, CO_2, and water

odied energy, primary uction	* 91	-	102	MJ/kg
footprint, primary uction	* 3.27	-	3.62	kg/kg
r usage	*108	-	324	l/kg
indicator 95	400			millipoints/kg
indicator 99	352			millipoints/kg

erial processing: energy

mer extrusion energy	* 5.86	-	6.47	MJ/kg
mer molding energy	* 19.7	-	21.7	MJ/kg
se machining energy (per wt removed)	* 1	-	1.11	MJ/kg
machining energy (per unit emoved)	* 5.76	-	6.37	MJ/kg
ding energy (per unit wt ved)	* 11	-	12.2	MJ/kg

erial processing: CO_2 footprint

mer extrusion CO_2	* 0.439	-	0.485	kg/kg
mer molding CO_2	* 1.47	-	1.63	kg/kg
se machining CO_2 (per unit emoved)	* 0.0753	-	0.0832	kg/kg
machining CO_2 (per unit wt	* 0.432	-	0.477	kg/kg

ved)				
ding CO_2 (per unit wt ved)	* 0.828	-	0.916	kg/kg

rial recycling: energy, CO_2, and recycle fraction

cle	TRUE			
odied energy, recycling	* 38	-	43	MJ/Kg
footprint, recycling	* 1.39	-	1.5	kg/kg
cle fraction in current ly	* 0.5	-	1	%
ncycle	TRUE			
bust for energy recovery	TRUE			
of combustion (net)	* 37.6	-	39.5	MJ/kg
bustion CO_2	* 3.06	-	3.22	kg/kg
dfill	TRUE			
egrade	FALSE			
city rating	Non-toxic			
newable resource?	FALSE			

cle mark:

ironmental notes

acrylonitrile monomer is nasty stuff, almost as poisonous as cyanide. Once polymerized with styrene it mes harmless. ABS if FDA compliant, can be recycled, and can be incinerated to recover the energy it ains.

porting information

ɜn guidelines

has the highest impact resistance of all polymers. It takes color well. Integral metallics are possible (as in 'lastics' Magix.) ABS is UV resistant for outdoor application if stabilizers are added. It is hygroscopic need to be oven dried before thermoforming) and can be damaged by petroleum-based machining oils. (acrylic-styrene-acrylonitrile) has very high gloss; its natural color is off-white but others are available. It ;ood chemical and temperature resistance and high impact resistance at low temperatures. UL-approved ɜs are available. SAN (styrene-acrylonitrile) has the good processing attributes of polystyrene but greater gth, stiffness, toughness, and chemical and heat resistance. By adding glass fiber the rigidity can be ased dramatically. It is transparent (over 90% in the visible range but less for UV light) and has good ·, depending on the amount of acrylonitrile that is added this can vary from water white to pale yellow, but ɔut a protective coating, sunlight causes yellowing and loss of strength, slowed by UV stabilizers. All three ɔe extruded, compression molded or formed to sheet that is then vacuum thermo-formed. They can be d by ultrasonic or hot-plate welding, or bonded with polyester, epoxy, isocyanate or nitrile-phenolic sives.

ınical notes

is a terpolymer—one made by copolymerizing 3 monomers: acrylonitrile, butadiene and styrene. The lonitrile gives thermal and chemical resistance, rubber-like butadiene gives ductility and strength, the ɛne gives a glossy surface, ease of machining and a lower cost. In ASA, the butadiene component (which s poor UV resistance) is replaced by an acrylic ester. Without the addition of butyl, ABS becomes, SAN— nilar material with lower impact resistance or toughness. It is the stiffest of the thermoplastics and has llent resistance to acids, alkalis, salts and many solvents.

ical uses

ty helmets; camper tops; automotive instrument panels and other interior components; pipe fittings; home- rity devices and housings for small appliances; communications equipment; business machines; plumbing ware; automobile grilles; wheel covers; mirror housings; refrigerator liners; luggage shells; tote trays; er shrouds; boat hulls; large components for recreational vehicles; weather seals; glass beading; gerator breaker strips; conduit; pipe for drain-waste-vent (DWV) systems.

enames

adex, Comalloy, Cycogel, Cycolac, Hanalac, Lastilac, Lupos, Lustran ABS, Magnum, Multibase, Novodur, fabs, Polylac, Porene, Ronfalin, Sinkral, Terluran, Toyolac, Tufrex, Ultrastyr

s

rence

essUniverse

ucers

*arranty is given for the accuracy of this data. Values marked * are estimates.*

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APPENDIX B

Metric Series Head Dimension Chart

Metric Series Head Dimension Chart

Dimensions pour divers styles de têtes de vis mécaniques

For Approximate Reference Only

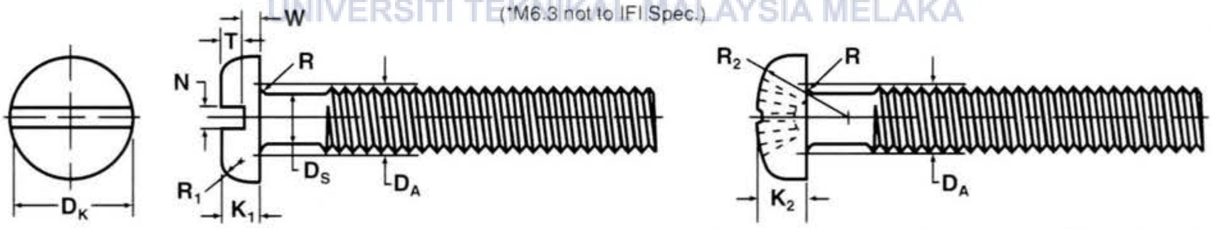
All Dimensions in Millimetres	Slotted CHEESE DIN 84		Slotted PAN DIN 85		Slotted OVAL DIN 964		Slotted FLAT DIN 963		Unslotted HEX CAP DIN 933/931		Phillips FLAT DIN 965		Phillips OVAL DIN 966		Phillips RAISED CHEESE DIN 7985	
DIA.	A	H	A	H	A	H	A	H	A	H	A	H	A	H	A	H
M1	2	0.7			1.9	0.6	1.9	0.6								
M1.2	2.3	0.8			2.3	0.72	2.3	0.72								
M1.4	2.6	0.9			2.6	0.84	2.6	0.84								
M1.6	3	1			3	0.96	3	0.96	3.2	1.1	3	0.96	3	0.96	3.2	1.3
M1.7	3.2	1.1							3.5	1.2						
M1.8	3.4	1.2														
M2	3.8	1.3			3.8	1.2	3.8	1.2	4	1.4	3.8	1.2	3.8	1.2	4	1.6
M2.3	4.4	1.5							4.5	1.6						
M2.5	4.5	1.6			4.7	1.5	4.7	1.5	5	1.7	4.7	1.5	4.7	1.5	5	2
M2.6	5	1.7							5	1.8						
M3	5.5	2	6	1.8	5.6	1.65	5.6	1.65	5.5	2	5.6	1.65	5.6	1.65	6	2.4
M3.5	6	2.4	7	2.1	6.5	1.93	6.5	1.93	6	2.4	6.5	1.93	6.5	1.93	7	2.7
M4	7	2.6	8	2.4	7.5	2.2	7.5	2.2	7	2.8	7.5	2.2	7.5	2.2	8	3.1
M5	8.5	3.3	10	3	9.2	2.5	9.2	2.5	8	3.5	9.2	2.5	9.2	2.5	10	3.8
M6	10	3.9	12	3.6	11	3	11	3	10	4	11	3	11	3	12	4.6
M8	13	5	16	4.8	14.5	4	14.5	4	13	5.5	14.5	4	14.5	4	16	6
M10	16	6	20	6	18	5	18	5	17	7	18	5	18	5	20	7.5

The approved NORTH AMERICAN STYLE, METRIC, SLOTTED and PHILLIPS PAN HEAD MACHINE SCREW fully meets the specifications of IFI 513, 1982. The head dimensions and contours differ from the European Style DIN 85, and instead, conform to the traditional style which is preferred by Canadian customers. The Metric coarse thread is interchangeable with all other coarse-threaded Metric fasteners as listed in this catalog.

MACHINE SCREWS - SLOTTED and PHILLIPS PAN HEAD

Head Style is to IFI 513, 1982

(*M6.3 not to IFI Spec.)



Nom Screw Size and Thread Pitch	D_S Body Dia.		D_K Head Dia.		K_1 Head Height Slotted Head		K_2 Head Height Phillips Head		R_1 Head Radius (Sltd.)	R_2 Head Radius (Phillips)	D_A Fillet Transition Dia.	R Fillet Radius	N Slot Width		T Slot Depth	W Unslotted Thickness
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Ref.	Max.	Min.	Max.	Min.	Min.	Min.
M2 x 0.4	2.00	1.65	4.0	3.7	1.3	1.1	1.6	1.4	0.8	3.2	2.6	0.1	0.7	0.5	0.5	0.4
M2.5 x 0.45	2.50	2.12	5.0	4.7	1.5	1.3	2.1	1.9	1.0	4.0	3.1	0.1	0.8	0.6	0.6	0.5
M3 x 0.5	3.00	2.58	5.6	5.3	1.8	1.6	2.4	2.2	1.2	5.0	3.5	0.1	1.0	0.8	0.7	0.7
M3.5 x 0.6	3.50	3.00	7.0	6.6	2.1	1.9	2.6	2.3	1.4	6.0	4.1	0.1	1.2	1.0	0.8	0.8
M4 x 0.7	4.00	3.43	8.0	7.6	2.4	2.2	3.1	2.8	1.6	6.5	4.7	0.2	1.5	1.2	1.0	0.9
M5 x 0.8	5.00	4.36	9.5	9.1	3.0	2.7	3.7	3.4	2.0	8.0	5.7	0.2	1.5	1.2	1.2	1.2
M6 x 1	6.00	5.21	12.0	11.5	3.6	3.3	4.6	4.3	2.5	10.0	6.8	0.3	1.9	1.6	1.4	1.4
M6.3 x 1*	6.30	5.51	12.0	11.6	3.9	3.5	4.3	4.0	2.5	13	-	0.3	1.9	1.6	1.7	1.4
M8 x 1.25	8.00	7.04	16.0	15.5	4.8	4.5	6.0	5.6	3.2	13.0	9.2	0.4	2.3	2.0	1.9	1.9
M10 x 1.5	10.00	8.86	20.0	19.4	6.0	5.7	7.5	7.1	4.0	16.0	11.2	0.4	2.8	2.5	2.4	2.4

APPENDIX C

Properties of air at 1atm

E A–15

rties of air at 1 atm pressure

Density ρ, kg/m^3	Specific Heat c_p, J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m^2/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m^2/s	Prandtl Number Pr
2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-5}	5.837×10^{-6}	0.7263
1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154
0.9718	1008	0.03024	3.086×10^{-5}	2.139×10^{-5}	2.201×10^{-5}	0.7132
0.9458	1009	0.03095	3.243×10^{-5}	2.181×10^{-5}	2.306×10^{-5}	0.7111
0.8977	1011	0.03235	3.565×10^{-5}	2.264×10^{-5}	2.522×10^{-5}	0.7073
0.8542	1013	0.03374	3.898×10^{-5}	2.345×10^{-5}	2.745×10^{-5}	0.7041
0.8148	1016	0.03511	4.241×10^{-5}	2.420×10^{-5}	2.975×10^{-5}	0.7014
0.7788	1019	0.03646	4.593×10^{-5}	2.504×10^{-5}	3.212×10^{-5}	0.6992
0.7459	1023	0.03779	4.954×10^{-5}	2.577×10^{-5}	3.455×10^{-5}	0.6974
0.6746	1033	0.04104	5.890×10^{-5}	2.760×10^{-5}	4.091×10^{-5}	0.6946
0.6158	1044	0.04418	6.871×10^{-5}	2.934×10^{-5}	4.765×10^{-5}	0.6935
0.5664	1056	0.04721	7.892×10^{-5}	3.101×10^{-5}	5.475×10^{-5}	0.6937
0.5243	1069	0.05015	8.951×10^{-5}	3.261×10^{-5}	6.219×10^{-5}	0.6948
0.4880	1081	0.05298	1.004×10^{-4}	3.415×10^{-5}	6.997×10^{-5}	0.6965
0.4565	1093	0.05572	1.117×10^{-4}	3.563×10^{-5}	7.806×10^{-5}	0.6986
0.4042	1115	0.06093	1.352×10^{-4}	3.846×10^{-5}	9.515×10^{-5}	0.7037
0.3627	1135	0.06581	1.598×10^{-4}	4.111×10^{-5}	1.133×10^{-4}	0.7092
0.3289	1153	0.07037	1.855×10^{-4}	4.362×10^{-5}	1.326×10^{-4}	0.7149
0.3008	1169	0.07465	2.122×10^{-4}	4.600×10^{-5}	1.529×10^{-4}	0.7206
0.2772	1184	0.07868	2.398×10^{-4}	4.826×10^{-5}	1.741×10^{-4}	0.7260
0.1990	1234	0.09599	3.908×10^{-4}	5.817×10^{-5}	2.922×10^{-4}	0.7478
0.1553	1264	0.11113	5.664×10^{-4}	6.630×10^{-5}	4.270×10^{-4}	0.7539

r ideal gases, the properties c_p, k, μ, and Pr are independent of pressure. The properties ρ, ν, and α at a pressure P (in atm) other than 1 atm are ned by multiplying the values of ρ at the given temperature by P and by dividing ν and α by P.

Data generated from the EES software developed by S. A. Klein and F. L. Alvarado. Original sources: Keenan, Chao, Keyes, Gas Tables, Wiley, 1984; rmophysical Properties of Matter. Vol. 3: Thermal Conductivity, Y. S. Touloukian, P. E. Liley, S. C. Saxena, Vol. 11: Viscosity, Y. S. Touloukian, S. C. and P. Hestermans, IFI/Plenun, NY, 1970, ISBN 0-306067020-8.

APPENDIX D

Hinge Drawing Specification

Flag Hinges

RoHS

(The photo is for left-hand use)

(The photo is for right-hand use)

Flag Hinges

HHPFLN (For Left-hand Use)

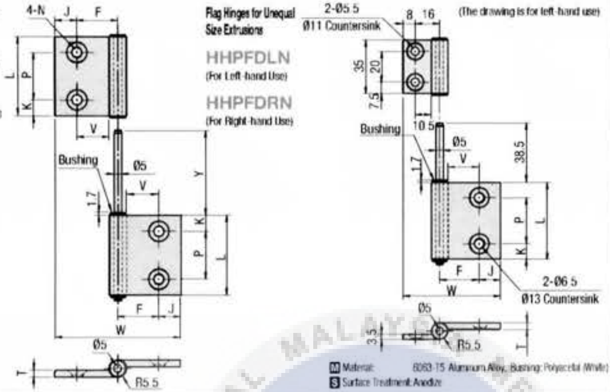
HHPFRN (For Right-hand Use)

Flag Hinges for Unequal Size Extrusions

HHPFDLN (For Left-hand Use)

HHPFDRN (For Right-hand Use)

(The drawing is for left-hand use)



M Material: 6063-T5 Aluminum Alloy, Bushing: Polyacetal (White)

S Surface Treatment: Anodize

Part Number Type	No.	*Allowable Load kg	N	Mass (g)	L	W	K	P	J	F	V	N Through	N Counterbore	T	Y	Unit Price 1-8 pc(s).	Volume Discount Rate 9~
HHPFLN HHPFRN	5	10	98	36	35	48	7.5	20	8	16	10.5	5.5	11	3.5	38.5		
	6			46	40	62	7.5	25	10	21	15.5	6.5	13		43.5		
	8	15	147	74	50	80	10	30	14	26	20.5			4.5	53.5		
	8-45			74	50	80	10	30	11.5	28.5	23						
HHPFDLN HHPFDRN	6	10	98	42	55	40	7.5	25	10	21	15.5	-		3.5	-		
	8	15	147	56	64	50	10	30	14	26	20.5			4.5			
	8-45					50	10	30	11.5	28.5	23						

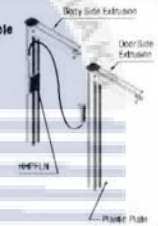
*The allowable load is the value when 2 pieces are used.

Ordering Example — Part Number: HHPFLN8-45

Days to Ship

Configure Online

ex Example

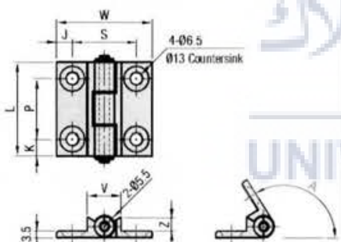


The hinge nuts on P.1115 are recommended when mating to panels, etc.

Stop Hinges

RoHS

HHPSNH



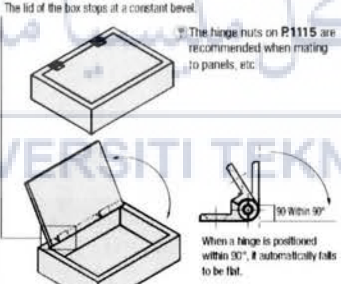
M Material: 6063-T5 Aluminum Alloy, Bushing: Polyacetal

S Surface Treatment: Clear Anodize

ex Example

The lid of the box stops at a constant bevel.

The hinge nuts on P.1115 are recommended when mating to panels, etc.



When a hinge is positioned within 90°, it automatically falls to be flat.

Part Number Type	No.	A (Angle)	*Allowable Load kg	N	Mass g	L	W	K	P	J	S	V	Z	Unit Price 1~8 pc(s).	Volume Discount Rate 9~
HHPSNH	6	120	10	98	37	47	48	8.5	30	8	32	17	6.8		
		135			36								5.4		
		150			35								4.2		
	8	120	10	98	58	63	62	13	37	10	42	21	7.3		
		135			56								5.8		
		150			55								4.5		

*The allowable load is the value when 2 pieces are used.

Ordering Example — Part Number - Angle: HHPSNH6 - 120

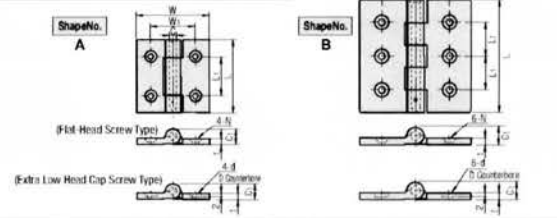
Days to Ship

Configure Online

Hinges for Heavy Loads

RoHS

Type Flat Head Screw Type	Type Extra Low Head Cap Screw Type	M Material	S Surface Treatment Hinge Plate	S Surface Treatment Shaft
HHSZ	HHSZT	316 Stainless Steel	Buffed Surface	-
HHSZD	-	Zinc Die Cast	Chrome Plating	-



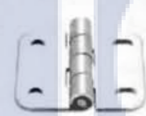
Part Number Type	L	Shape No.	W	W_1	L_1	C	C_1	t	HHSZ, HHSZD N Through	HHSZ, HHSZD N Countersink	HHSZT D	HHSZT d	Division	*Allowable Load (N)	Weight (g)	HHSZ Unit Price 1-19 pc(s).	HHSZ Volume Discount Rate 20~	HHSZD Unit Price 1-19 pc(s).	HHSZD Volume Discount Rate 20~	HHSZT Unit Price 1-19 pc(s).	HHSZT Volume Discount Rate 20~
HHSZ HHSZD HHSZT	50	A	50	35	20	6	14	5	4.4	8.6	8.6	4.6	3	350	110						
	65		65	40	35				5.6	10.6	9.6	5.6		450	190						
	75		75	50	40	8	16	6	6.6	12.6	10.6	6.6		650	305						
	100	B	100	60	30								5	850	500			-	-		
	125		100	60	37.5	8	16	6	6.6	12.6	-	-	5	1000	650			-	-	-	-

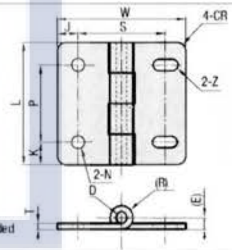
*The allowable load is the value when 2 pieces are used.

Hinges with Slotted Holes

RoHS

SHPSNA





The hinge nuts on P.1115 are recommended when mating to panels, etc.

M Material: 304 Stainless Steel

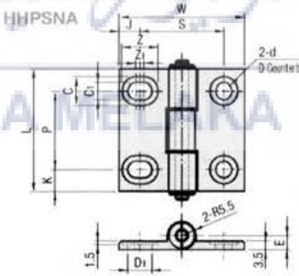
Part Number Type	No.	*Allowable Load kg	N	Mass (g)	L	W	K	P	J	S	N	Z	T	(E)	(R)	CR	D	Unit Price 1-19 pc(s).	Volume Discount Rate 20~
SHPSNA	5	9	88	34	41	36	8	25	7.5	21	5.5	5.5x6.5	2	4.6	4.6	4	5		
	6	12	117	48	48	48	9	30	8	32		5.5x10							
	8	25	245	111	59	62	11	37	10	42	6.5	6.5x10	3	6.1	6.1	5	6		

*The allowable load is the value when 2 pieces are used.

Aluminum Hinges with Slotted Holes

RoHS

HHPSNA

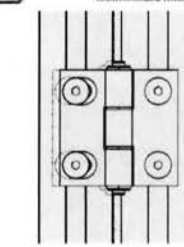


M Material: 6063 Aluminum Alloy, Bushing: Polyacetal

S Surface Treatment: Clear Anodize

ex Example

The hinge nuts on P.1115 are recommended when mating to panels, etc.



Slotted mounting holes make it possible to adjust right and left positions.

Part Number Type	No.	*Allowable Load kg	N	Mass g	L	W	K	P	J	S	d Through	D Counterbore	D_1	C	C_1	Z	Z_1	E	Unit Price 1-8 pc(s).	Volume Discount Rate 9~
HHPSNA	5	10	98	22	47	36	11	25	7.5	21	5.5	10	7	10	5.5	11.5	1.5	5		
	6			32		48	8.5	30	8	32	6.5	11	9.5	11	6.5	14	3	5.5		
	[illegible]			47	63	62	13	37	10	42			11.5			16	5			

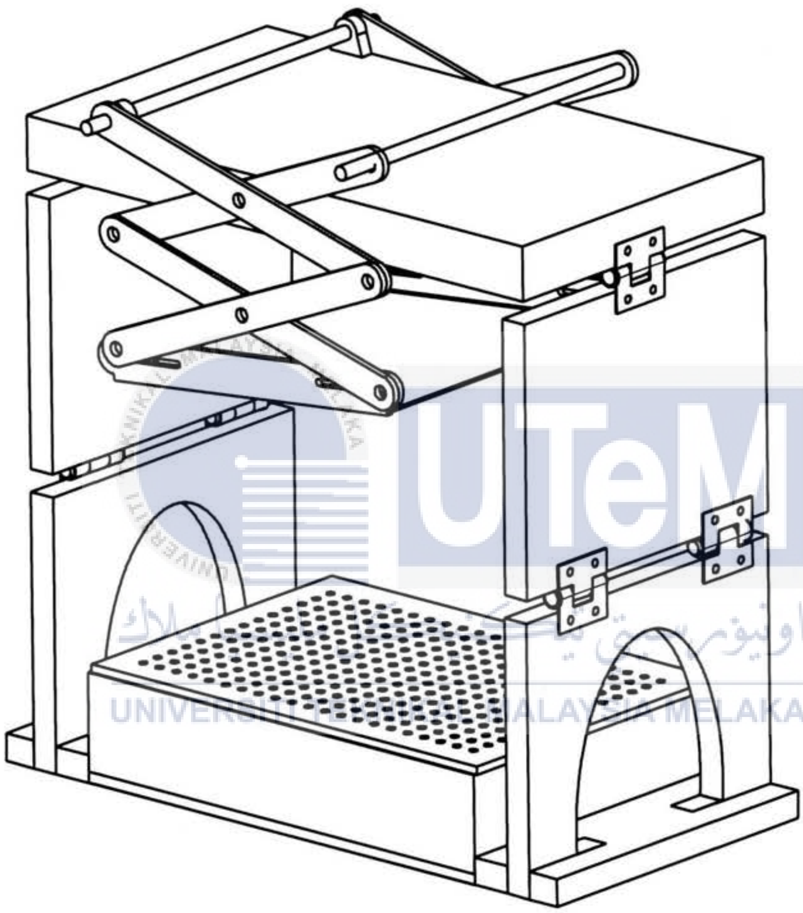
Ordering Example — Part Number: HHSZ65, SHPSNA5, HHPSNA8

Days to Ship

Configure Online

APPENDIX E

Assembly Drawing of Vacuum Forming Machine

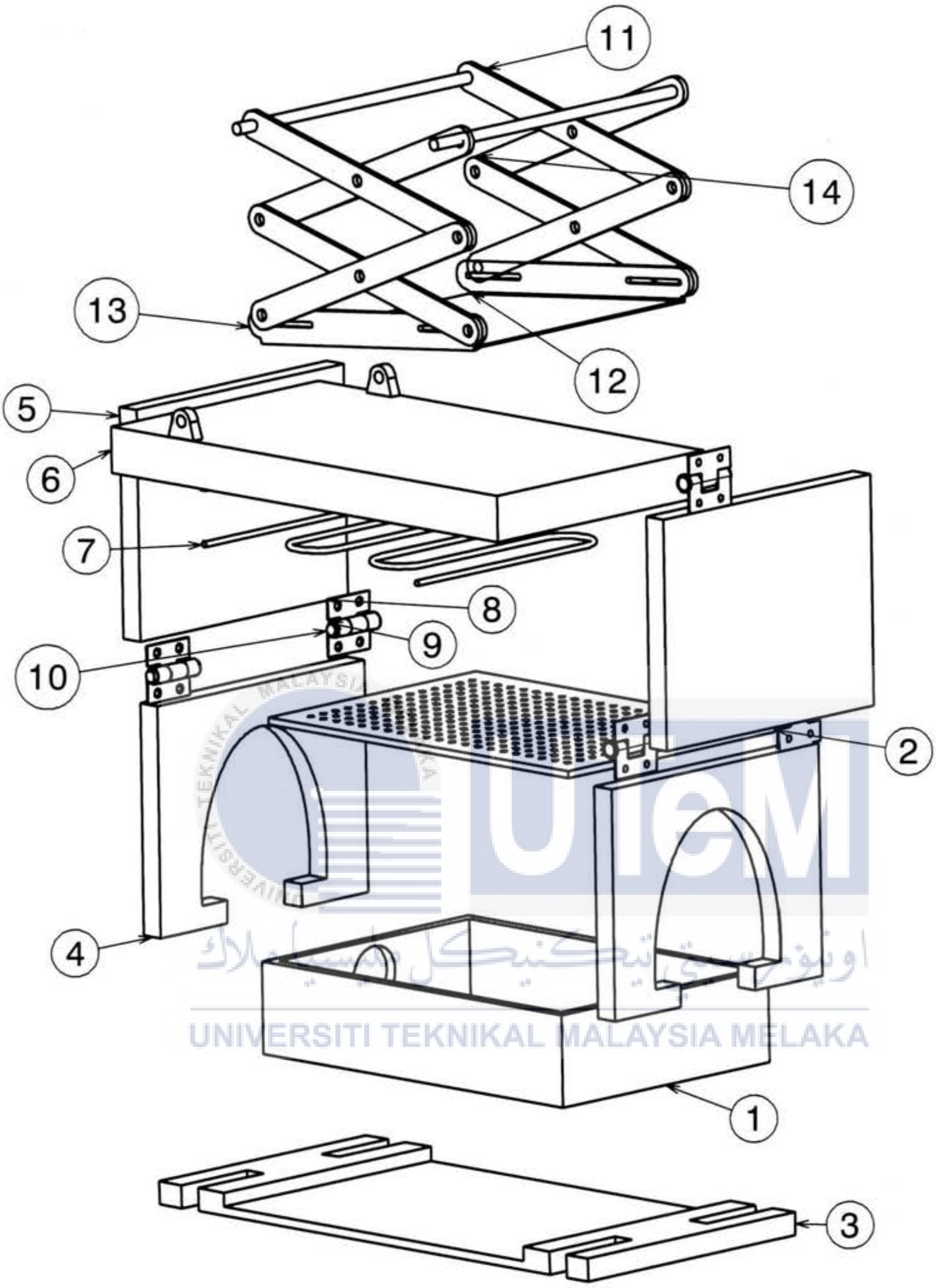


drawing is our property. an't be reproduced ommunicated without written agreement.		UNIVERSITI TEKNIKAL MALAYSIA MELAKA			
N BY	DATE	DRAWING TITLE ASSEMBLY VIEW OF VACUUM FORMING MACHINE			
n Chun Yok	17-Mar-17				
KED BY	DATE	SIZE	DRAWING NUMBER		REV
	XXX	A4	XXX		X
GNED BY	DATE	SCALE 1:5	WEIGHT (kg) XXX	SHEET	2/9
n Chun Yok	12-Mar-17				

APPENDIX F

Exploded Drawing of Vacuum Forming Machine

D | C | B | A



4
3
2
1

drawing is our property. an't be reproduced ommunicated without written agreement.		UNIVERSITI TEKNIKAL MALAYSIA MELAKA				
N BY n Chun Yok	DATE 17-Mar-17	DRAWING TITLE EXPLODED VIEW OF VACUUM FORMING MACHINE				
KED BY	DATE XXX	SIZE A4	DRAWING NUMBER XXX			REV X
GNED BY n Chun Yok	DATE 12-Mar-17	SCALE 1:1	WEIGHT(kg) XXX		SHEET 3/9	

D | A

Bill of Material: Product8

Number	Part Number	Quantity	Type
1	Vaccum Box	1	Part
2	Hole plate	1	Part
3	Base	1	Part
4	Bottom Support	2	Part
5	Upper Support	2	Part
	Hinge	5	Assembly
6	Cover plate	1	Part
	Scissor lift	1	Assembly
7	heaing element	1	Part

Bill of Material: Hinge

Number	Part Number	Quantity	Type
8	HInge part (T plate)	1	Part
9	HInge part (U plate)	1	Part
10	HInge part (rod)	1	Part

Bill of Material: Scissor lift

Number	Part Number	Quantity	Type
11	Scissor lift part(Rod)	2	Part
	Stick Assembly	2	Assembly
12	Plastic sheet	1	Part
13	Scissor lift part (sliding stick)	2	Part

Bill of Material: Stick Assembly

Number	Part Number	Quantity	Type
14	Stick	4	Part

D BY:
in Chun Yok
20-Mar-17
BY:
XXX
XXX

4

FINAL YEAR PROJECT

WEIGHT (kg): -

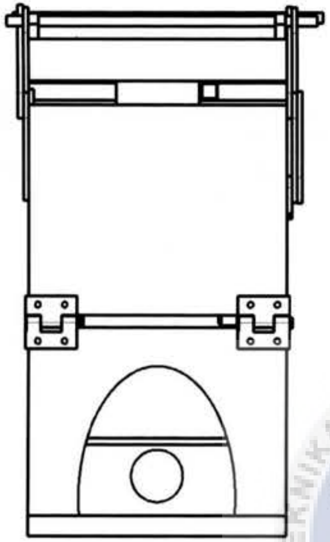
DRAWING NUMBER: BILL OF MATERIALS

SHEET: -

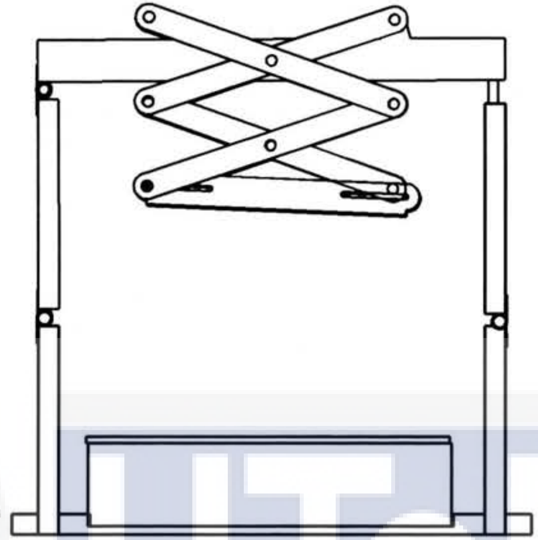
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

APPENDIX G

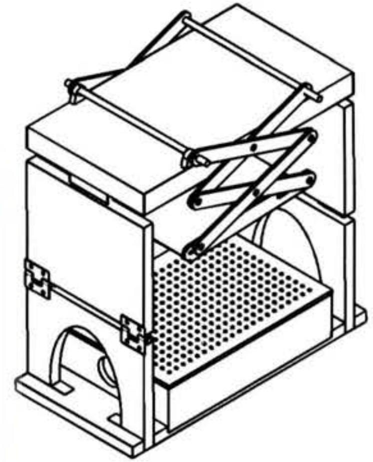
Part Drawing of Vacuum Forming Machine



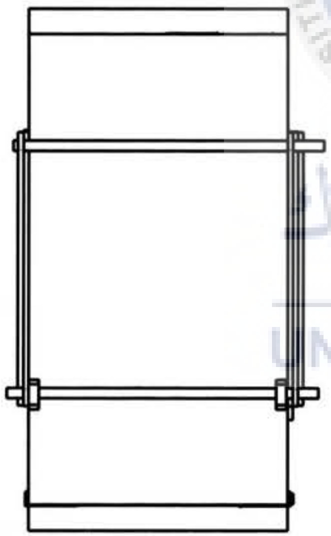
Front view
Scale: 1:7



Left view
Scale: 1:7

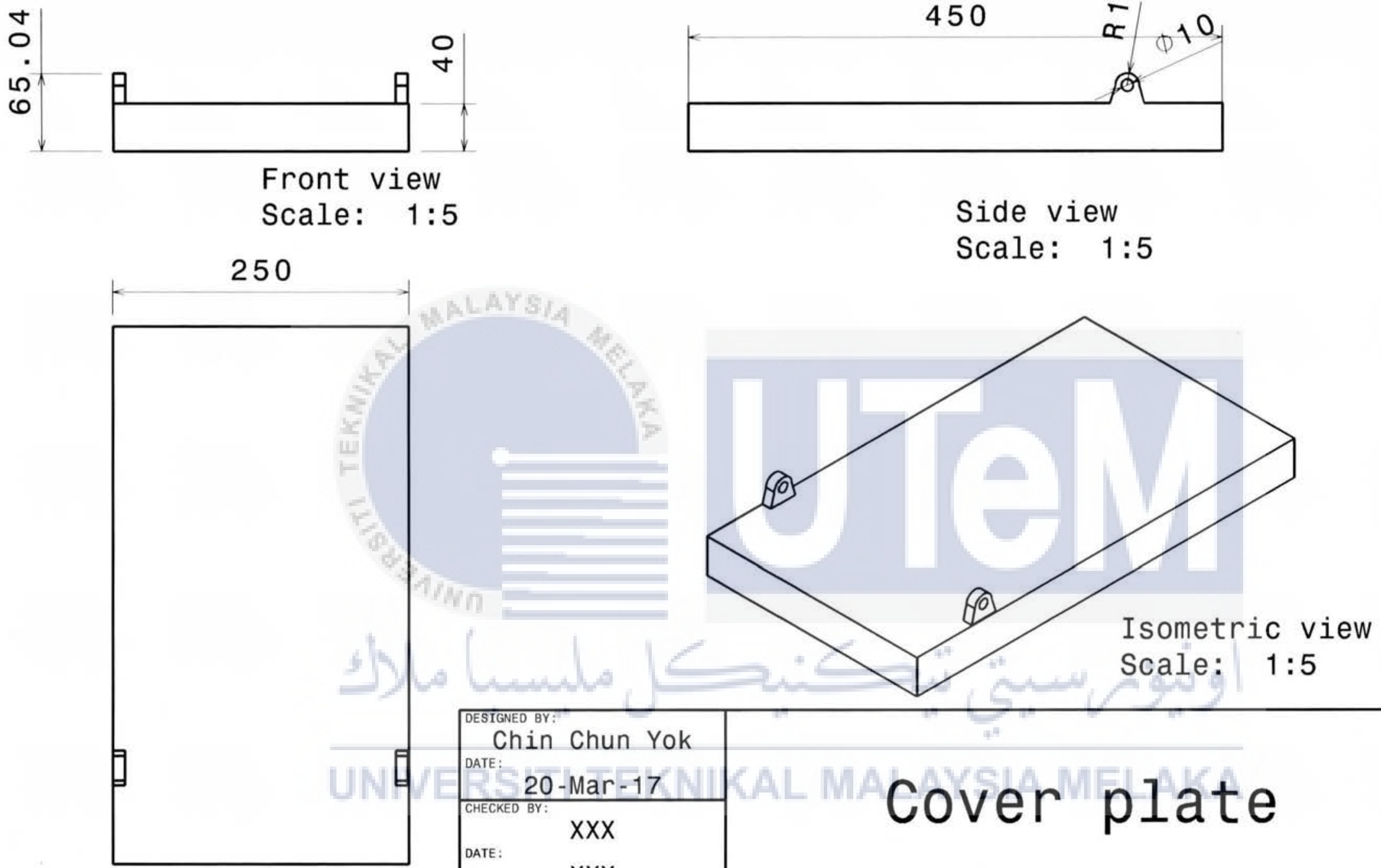


Isometric view
Scale: 1:11



Top view
Scale: 1:7

DESIGNED BY: Chin Chun Yok	Isometric view	I	–
DATE: 20-Mar-17		H	–
CHECKED BY: XXX		G	–
DATE: XXX		F	–
SIZE A4	Vacuum forming machine	E	–
		D	–
SCALE 1:7 / WEIGHT (kg) XXX	Final year project / SHEET 1/1	C	–
		B	–
		A	–



DESIGNED BY: Chin Chun Yok
DATE: 20-Mar-17
CHECKED BY: XXX
DATE: XXX

Cover plate

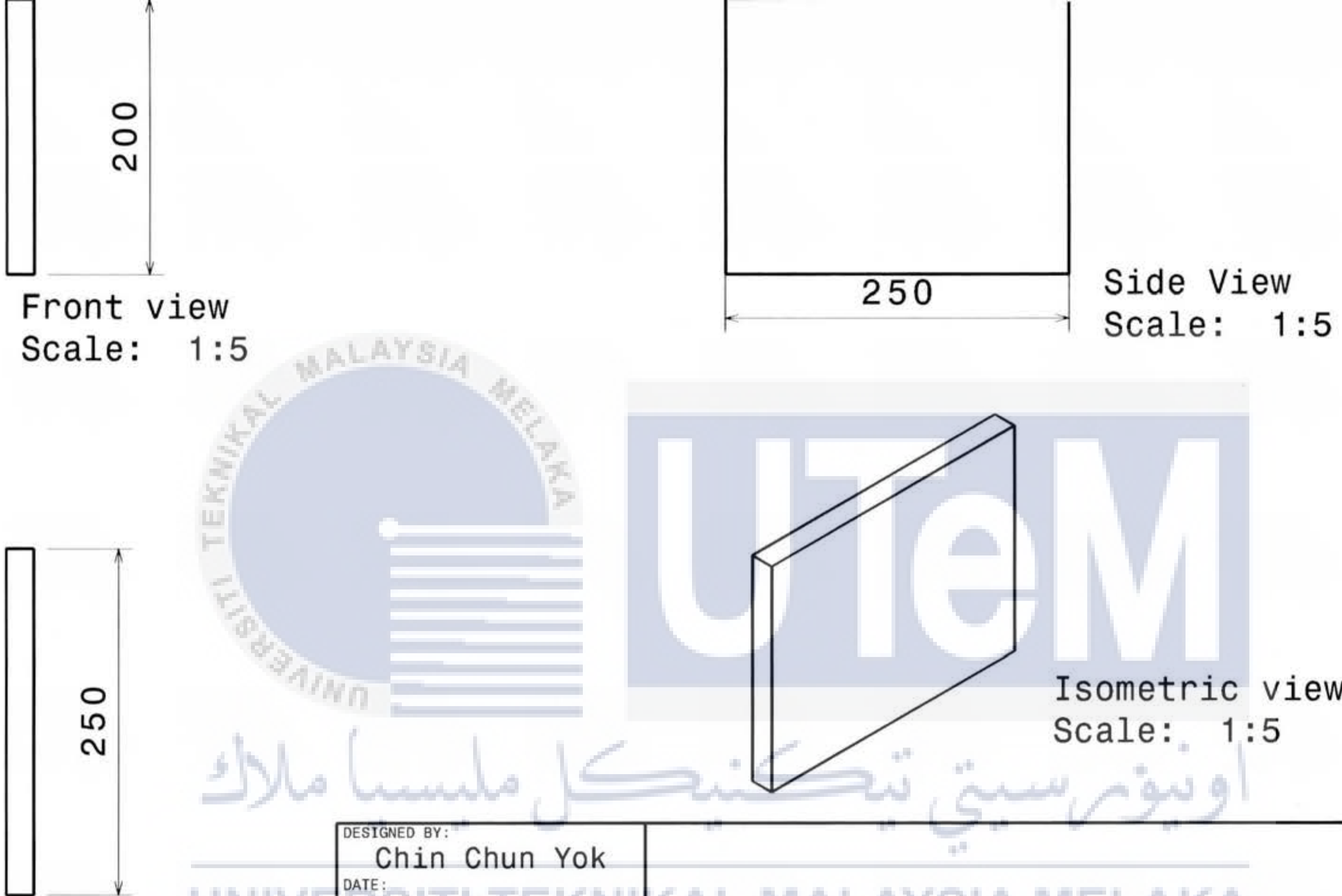
SIZE: A4
SCALE: 1:5
WEIGHT (kg): XXX

Vacuum forming machine

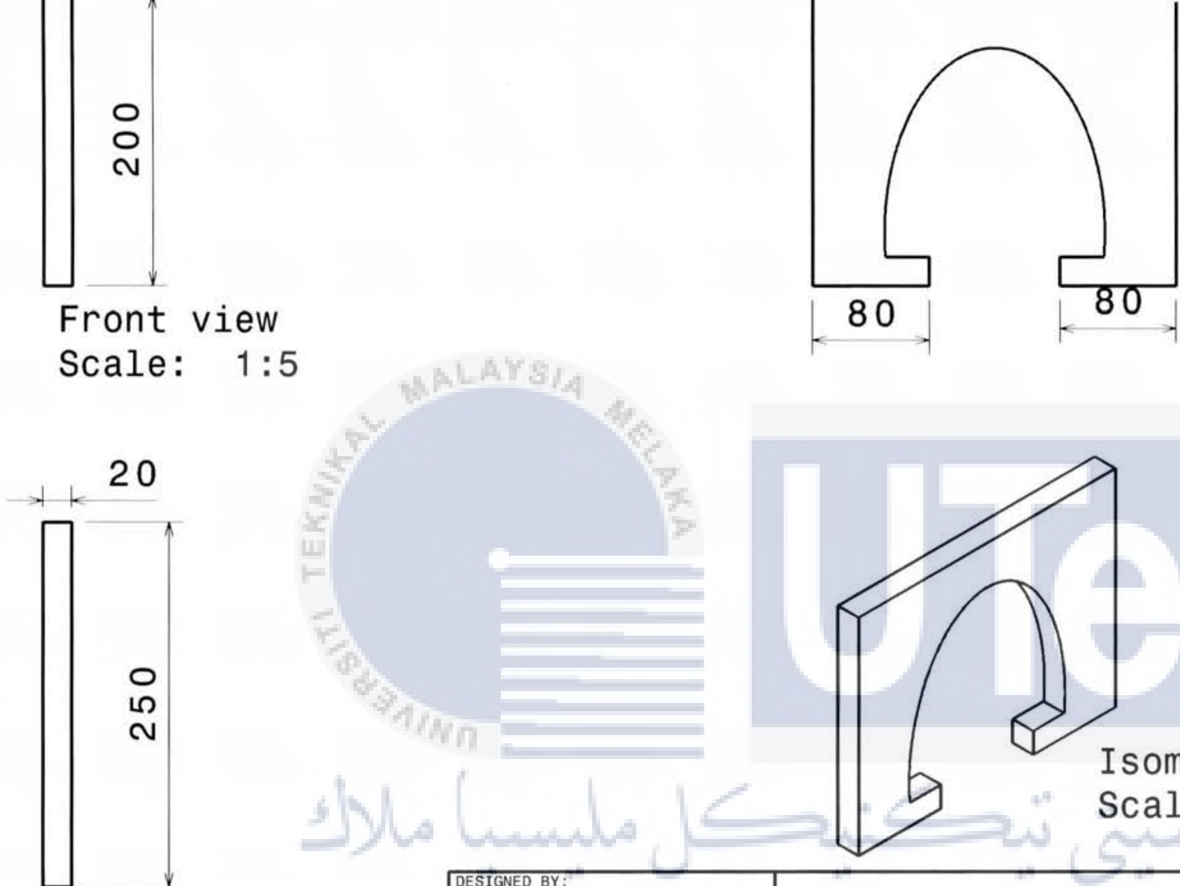
Final year project

SHEET: 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_



DESIGNED BY: Chin Chun Yok		Upper Support	I	_
DATE: 20-Mar-17			H	_
CHECKED BY: XXX			G	_
DATE: XXX			F	_
SIZE A4		Vacuum forming machine	E	_
			D	_
SCALE	WEIGHT (kg)	DRAWING NUMBER / SHEET	C	_
1:5	XXX	Final year project / 1/1	B	_
This drawing is our property; it can't be reproduced or communicated without our written agreement.			A	_



Front view
Scale: 1:5

Side view
Scale: 1:5

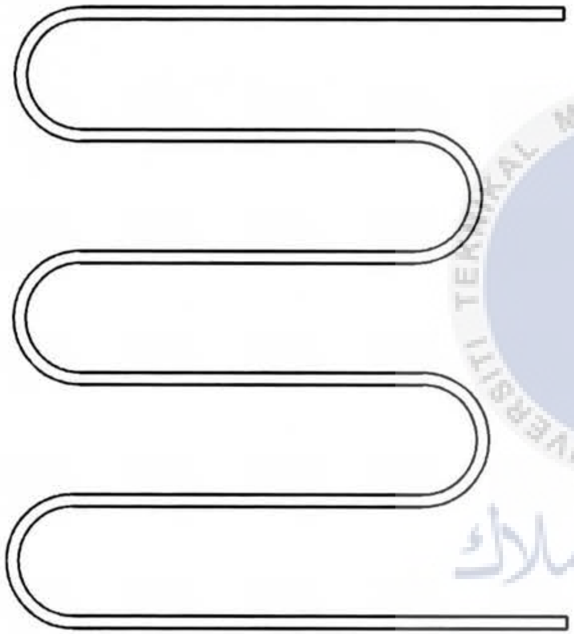
Top view
Scale: 1:5

Isometric view
Scale: 1:5

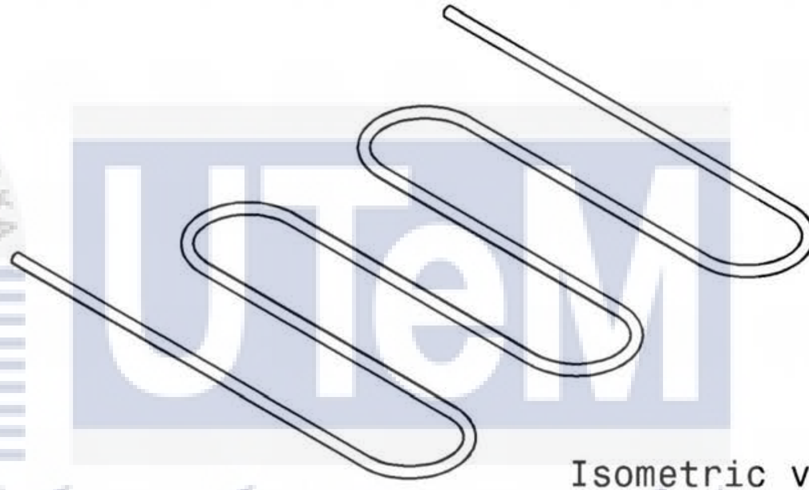
DESIGNED BY: Chin Chun Yok	Bottom Support		I	_
DATE: 20-Mar-17			H	_
CHECKED BY: XXX			G	_
DATE: XXX			F	_
SIZE A4	Vacuum forming machine		E	_
			D	_
SCALE 1:5	WEIGHT (kg) XXX	Final year project	SHEET 1/1	C	_
			B	_
This drawing is our property; it can't be reproduced or communicated without our written agreement.			A	_

Front view
Scale: 1:3

Side view
Scale: 1:3



Top view
Scale: 1:3



Isometric view
Scale: 1:3

DESIGNED BY: Chin Chun Yok		Heating element	I –
DATE: 20-Mar-17			H –
CHECKED BY: XXX			G –
DATE: XXX			F –
SIZE A4		Vacuum forming machine	E –
			D –
SCALE 1:3	WEIGHT (kg) XXX	Final year project / SHEET 1/1	C –
			B –
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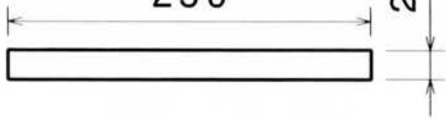
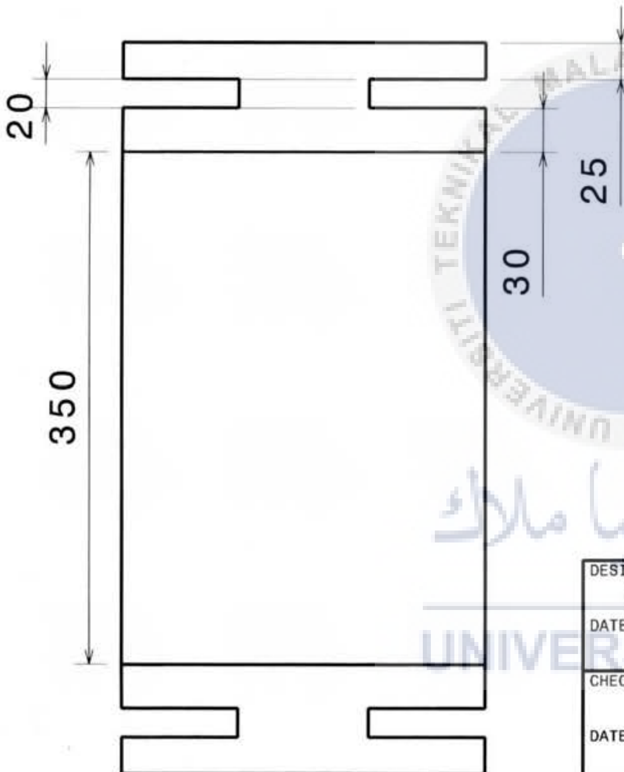
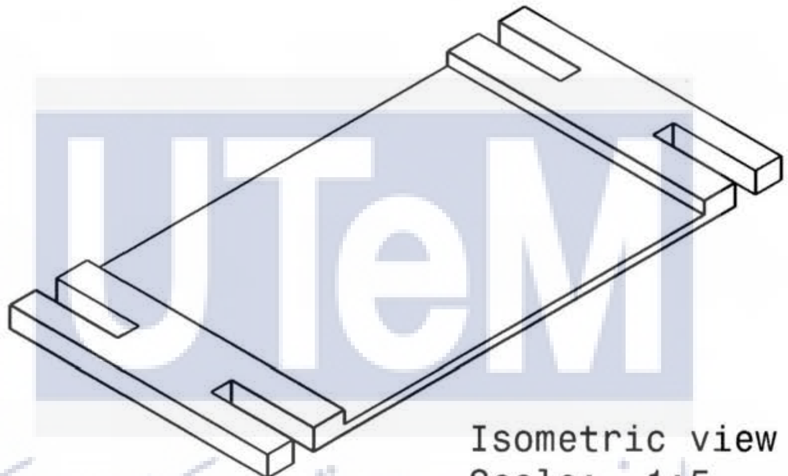


Front view
Scale: 1:5

Side view
Scale: 1:5



Top view
Scale: 1:5



Isometric view
Scale: 1:5

DESIGNED BY: Chin Chun Yok	Base	I	_
DATE: 20-Mar-17		H	_
CHECKED BY: XXX		G	_
DATE: XXX		F	_
SIZE A4	Vacuum forming machine	E	_
		D	_
SCALE 1:5 / WEIGHT (kg) XXX	Final year project / SHEET 1/1	C	_
		B	_
		A	_

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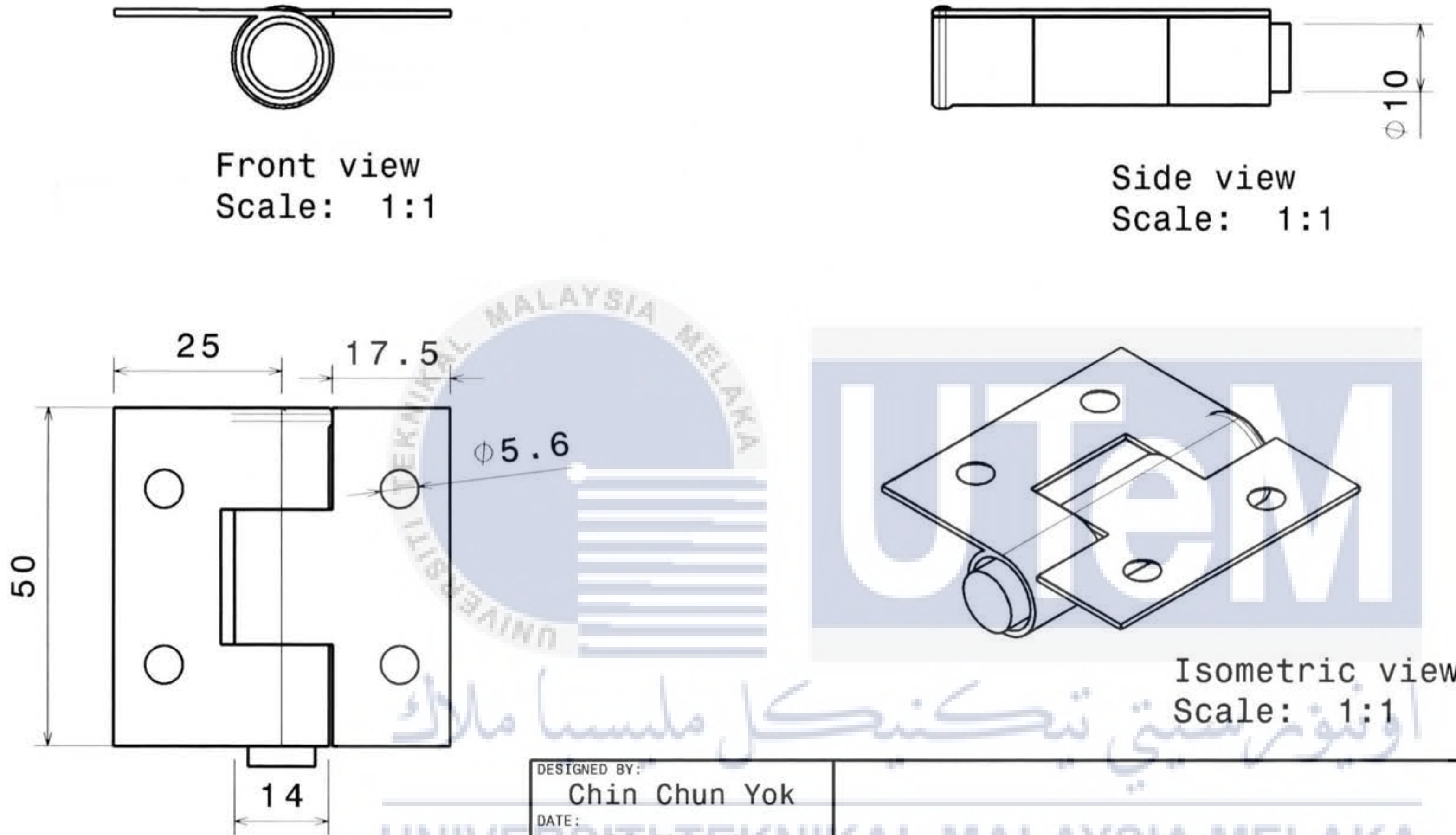
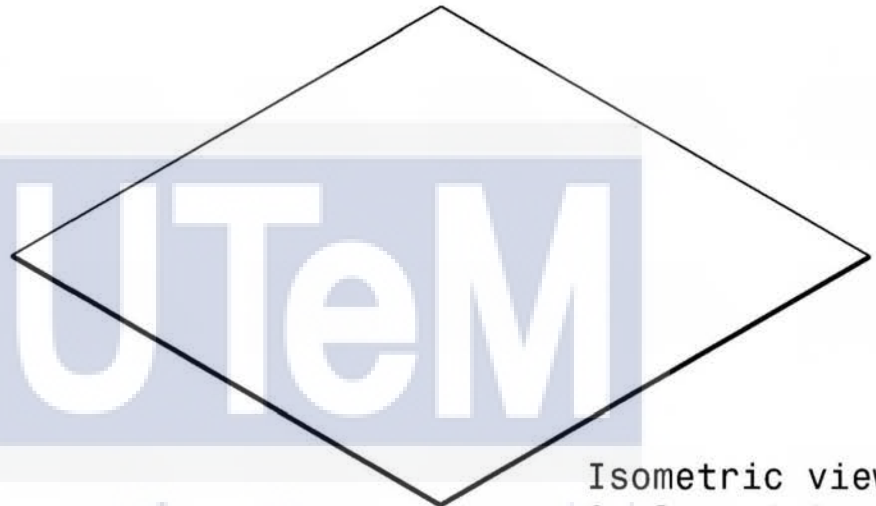


DESIGNED BY: Chin Chun Yok	Hinge
DATE: 20-Mar-17	
CHECKED BY: XXX	
DATE: XXX	
SIZE A4	Vacuum forming machine
SCALE 1:1 / WEIGHT (kg) XXX	Final year project / SHEET 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

Front view
Scale: 1:3

Side view
Scale: 1:3



Isometric view
Scale: 1:3

Top view
Scale: 1:3

DESIGNED BY: Chin Chun Yok DATE: 20-Mar-17		Plastic sheet	I	_
CHECKED BY: XXX DATE: XXX			H	_
SIZE A4		Vacuum forming machine	G	_
SCALE 1:3	WEIGHT (kg) XXX	Final year project	F	_
		SHEET 1/1	E	_
			D	_
			C	_
			B	_
			A	_

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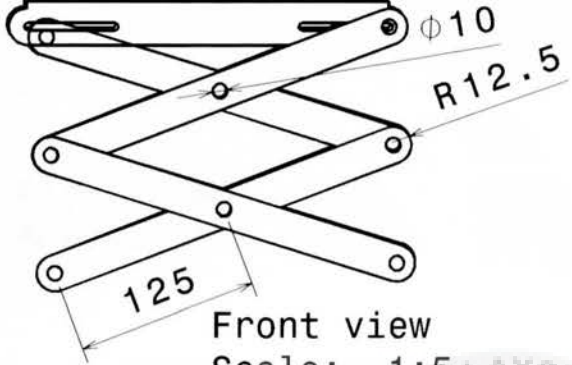
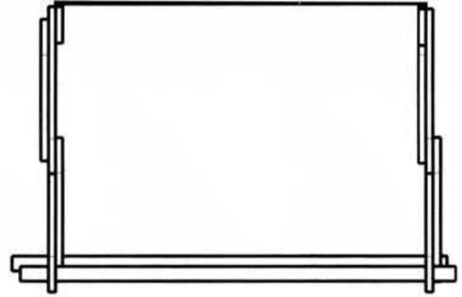
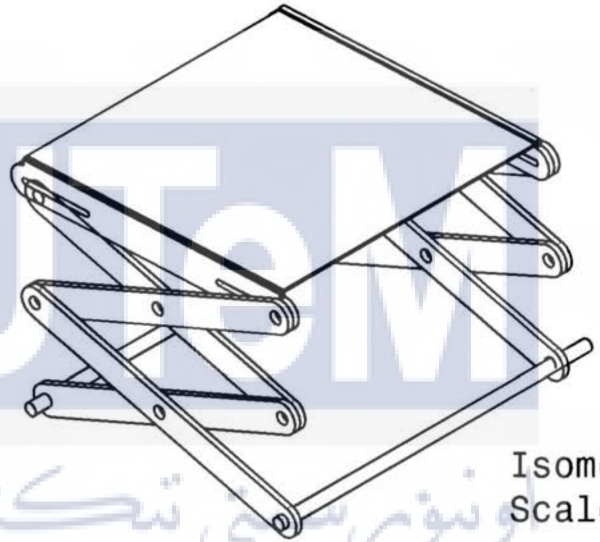


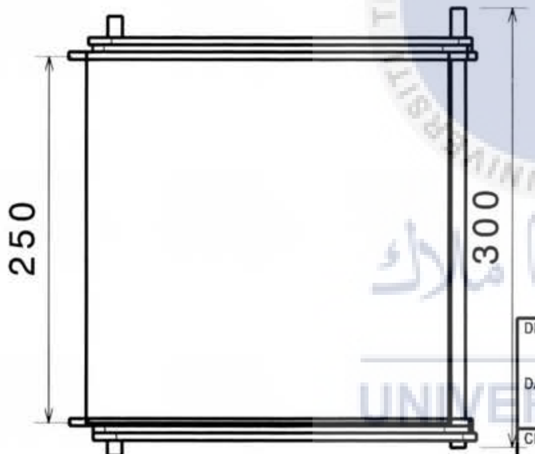
Front view
Scale: 1:5



Side view
Scale: 1:5



Isometric view
Scale: 1:5

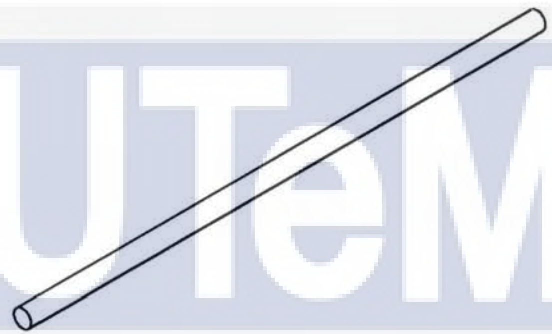


Top view
Scale: 1:5

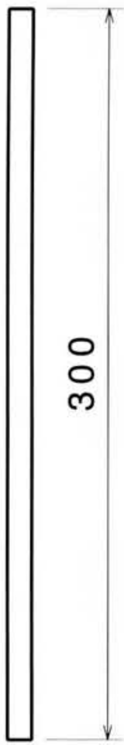
DESIGNED BY: Chin Chun Yok DATE: 20-Mar-17	Scissor lift	I	_
		H	_
CHECKED BY: XXX DATE: XXX		G	_
		F	_
SIZE A4	Vacuum forming machine	E	_
		D	_
SCALE 1:5 / WEIGHT (kg) XXX	Final year project / SHEET 1/1	C	_
		B	_
This drawing is our property; it can't be reproduced or communicated without our written agreement.		A	_

Front view
Scale: 1:3

Side view
Scale: 1:3



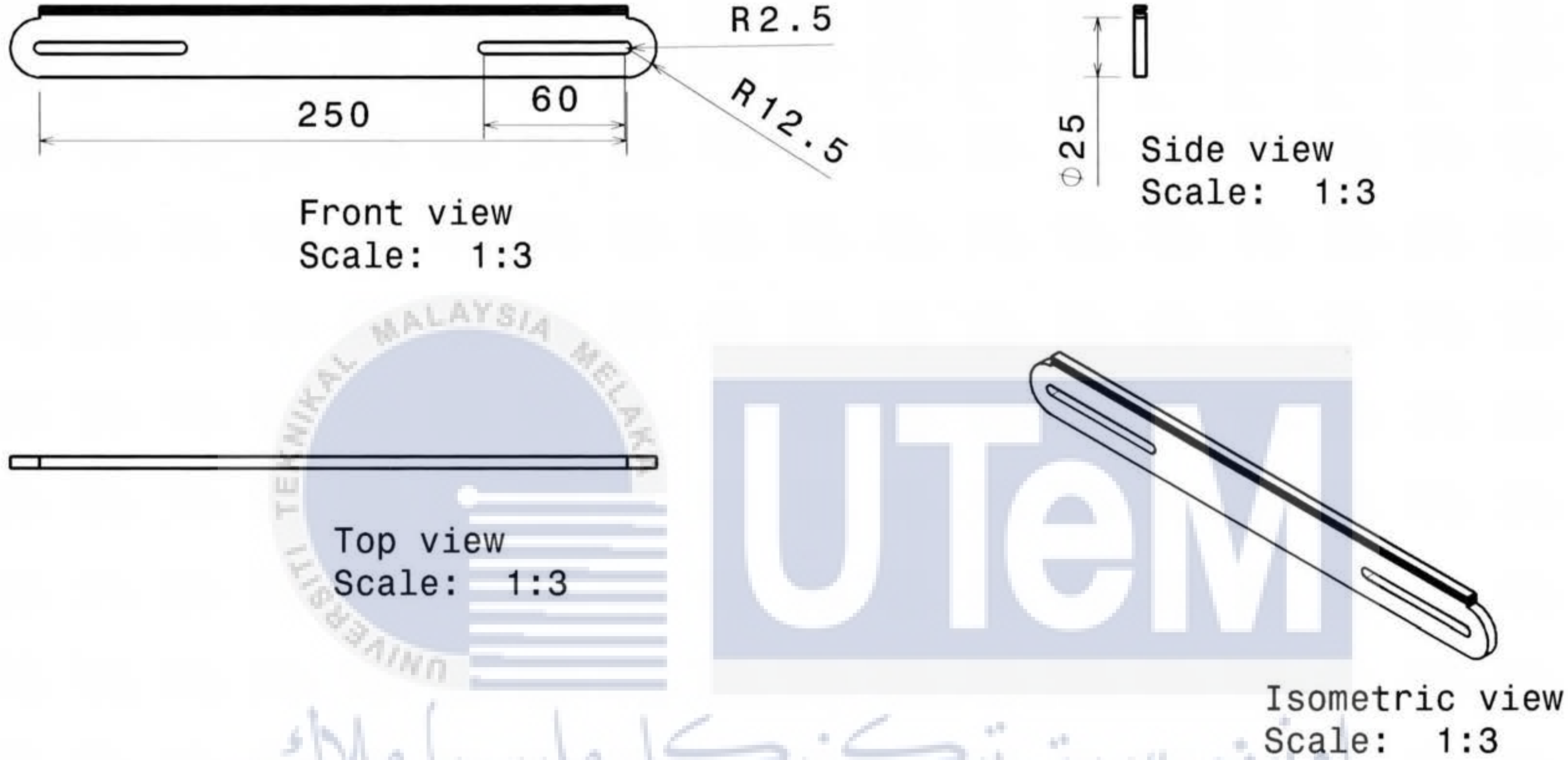
Isometric view
Scale: 1:3



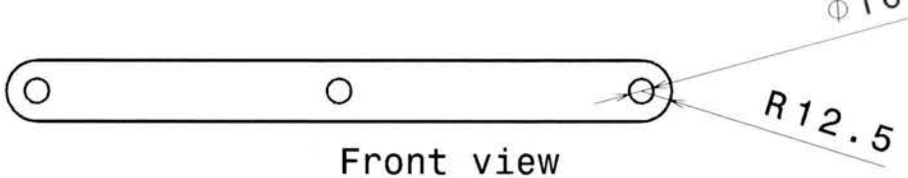
Top view
Scale: 1:3

DESIGNED BY: Chin Chun Yok		Scissor lift rod	
DATE: 20-Mar-17			
CHECKED BY: XXX			
DATE: XXX			
SIZE A4		Vacuum forming machine	
SCALE 1:3	WEIGHT (kg) XXX	Final year project	SHEET 1/1

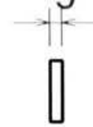
I	–
H	–
G	–
F	–
E	–
D	–
C	–
B	–
A	–



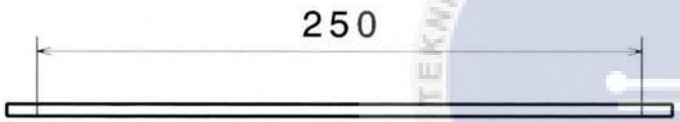
DESIGNED BY: Chin Chun Yok		Scissor lifter sliding stick	I –
DATE: 20-Mar-17			H –
CHECKED BY: XXX			G –
DATE: XXX			F –
SIZE A4		Vacuum forming machine	E – / D –
SCALE 1:3	WEIGHT (kg) XXX	Final year project	SHEET 1/1 · C – / B –
This drawing is our property; it can't be reproduced or communicated without our written agreement.			A –



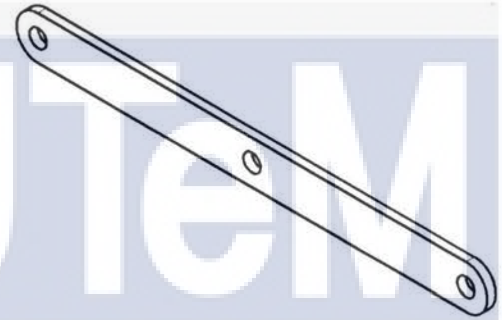
Front view
Scale: 1:3



Side view
Scale: 1:3



Top view
Scale: 1:3



Isometric view
Scale: 1:3

DESIGNED BY: Chin Chun Yok	Scissor lift stick		I	–
DATE: 20-Mar-17			H	–
CHECKED BY: XXX			G	–
DATE: XXX			F	–
SIZE A4		Vacuum forming machine	E	–
			D	–
SCALE 1:3	WEIGHT (kg) XXX	Final year project	SHEET 1/1	C	–
			B	–
			A	–

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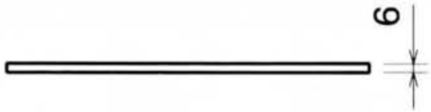
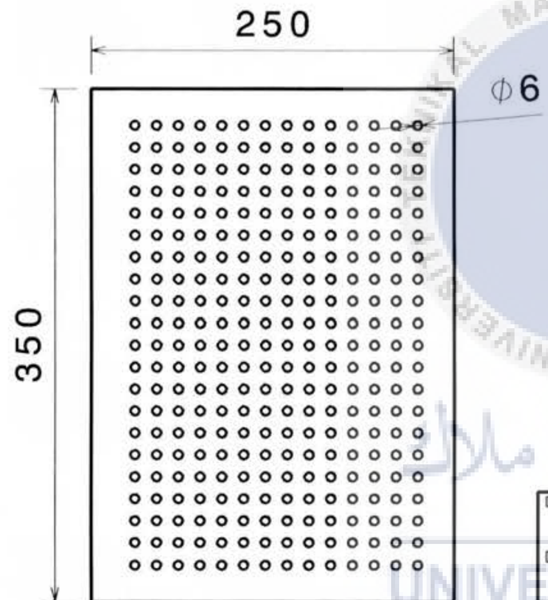
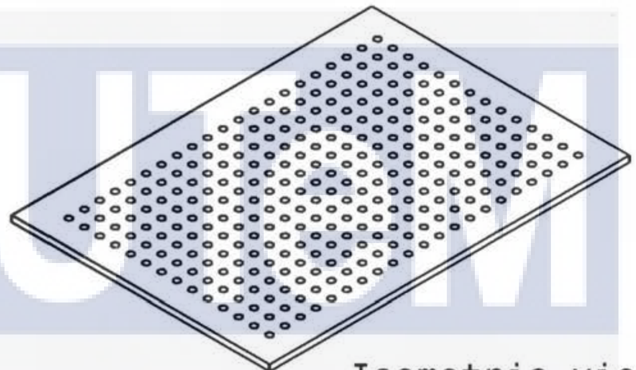


Front view
Scale: 1:5

Side view
Scale: 1:5

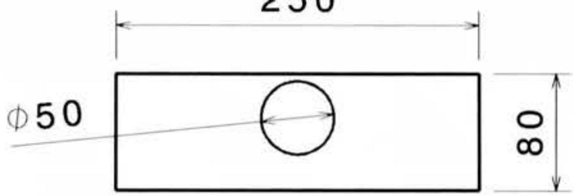


Top view
Scale: 1:5



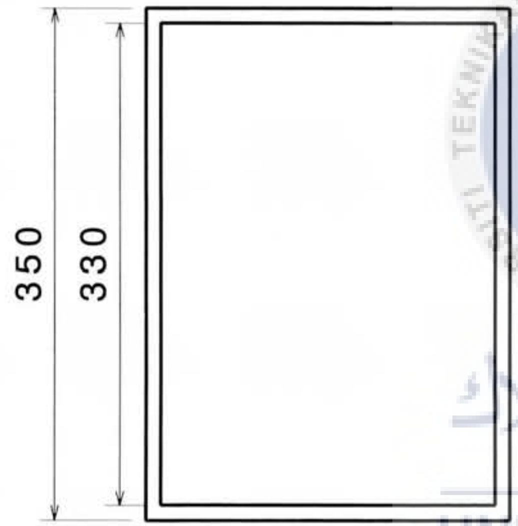
Isometric view
Scale: 1:5

DESIGNED BY: Chin Chun Yok	Hole Plate		I –
DATE: 20-Mar-17			H –
CHECKED BY: XXX			G –
DATE: XXX			F –
SIZE A4			E –
	Vacuum forming machine		D –
SCALE 1:5	WEIGHT (kg) XXX		C –
	Final year project	SHEET 1/1	B –
This drawing is our property; it can't be reproduced or communicated without our written agreement.			A –

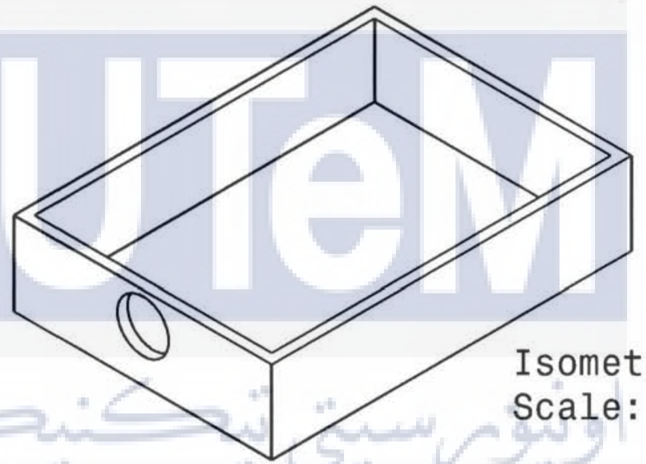


Front view
Scale: 1:5

Side View
Scale: 1:5



Top view
Scale: 1:5



Isometric view
Scale: 1:5

DESIGNED BY: Chin Chun Yok DATE: 20-Mar-17 CHECKED BY: XXX DATE: XXX		Vacuum Box		I –
				H –
				G –
				F –
SIZE A4		Vacuum forming machine		E –
				D –
SCALE 1:5	WEIGHT (kg) XXX	Final year project	SHEET 1/1	C –
				B –
This drawing is our property; it can't be reproduced or communicated without our written agreement.				A –