UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **<u>EFFECT OF CASTING TEMPERATURE ON DIMENSIONAL ACCURACY IN GRAVITY CASTING</u>**

SESI PENGAJIAN: <u>2009/2010</u>

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FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Effect of Casting Temperature on Dimensional Accuracy in Gravity Casting*" is written by Mohd Shariman Bin Razali. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Examiner

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EFFECT OF CASTING TEMPERATURE ON DIMENSIONAL ACCUARCY IN GRAVITY CASTING

MOHD SHARIMAN BIN RAZALI

Thesis submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2009

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SUPERVISOR'S AND CO-SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
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Dedicated to my parents

My siblings

My supervisor and co-supervisor

And all my friends

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ABSTRACT

In casting process the dimension of the final products is not accurate compared to the dimension of master pattern. This study is conducted to investigate the effect of casting temperature to the dimensional accuracy of the final products. In this study, wax holder is produced using gravity casting. The objective of this study is to investigate the effect of casting temperature on dimensional accuracy on the final product using gravity casting. Also, to find optimum melting temperature of paraffin wax in terms of dimensional accuracy of the final product compare with master pattern. In this process, three different setting of melting temperature are applied, which are 47°C, 55°C and 64°C. The dimension of final product is measured using vernier calipers. All the data are plotted as bar graph. From the graph, it showed that melting temperature 55°C have the best dimensional accuracy and low percentage of error compared with other melting temperature.

ABSTRAK

Di dalam process tuangan dimensi produk yang telah dihasilkan tidak tepat jika dibandingkan dengan dimensi paten utama. Kajian ini di buat untuk menyiasat kesan suhu semasa tuangan ke atas ketepatan dimensi produk akhir. Di dalam kajian ini, bekas lilin dihasilkan menggunakan tuangan graviti. Objektif utama kajian ini adalah untuk mengkaji kesan suhu ke atas ketepatan dimensi produk akhir menggunakan tuangan graviti. Kajian ini juga dijalankan untuk mencari suhu cair lilin paraffin yang paling optimum untuk mendapatkan ketepatan dimensi produk akhir yang terbaik antara paten utama. Dalam kajian ini, tiga suhu yang berlainan digunakan iaitu 47°C, 55°C dan 64°C. Dimensi produk akhir diukur menggunakan angkup vernier. Semua data yang diperoleh diplotkan sebagai graf bar. Daripada graf, ia menunjukkan suhur cair 55°C mempunyai ketepatan dimensi yang paling baik dan peratus ralat yang rendah berbanding suhu cair yang lain.

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ºC	Degree Celsius
mm	Millimeter
%	Percentages
g/cm^3	Gram per Centimeter Cube
ºF	Degree Fahrenheit
J/gK	Joule per Gram per Kelvin
min	Minute
N	Newton

LIST OF ABBREVIATIONS

RTV	Room Temperature Vulcanizing
CAD	Computer Aided Design
RT	Rapid Tooling
RP	Rapid Prototyping
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Castings have several characteristics that clearly define their role in modern equipment used for transportation, communication, power, agriculture, construction, and in industry. Gravity casting is one of the types of casting. The process involves the gravity force for the molten wax or metal to fill up the mould. The main problem in gravity casting is the dimensional accuracy of the final product is not accurate compared to the final product that had been produced. Higher pouring temperature causes shrinkage of the casting and mould warping (Grill P. L., 1985). Pouring temperature had been one of the factors that affected the dimensional accuracy of casting's product. This study will investigate the effect of different temperature to the dimensional accuracy of the final product by gravity casting.

1.2 OBJECTIVE OF THE STUDY

This study is focused on the applications of casting technology to produce a final part of wax holder, where the main objective is to study the effect of casting temperature to the dimensional accuracy of final part by gravity casting.

1.3 SCOPE OF THE STUDY

The scopes of the study are:

(i) To study the difference of dimensional accuracy between pattern compared to the final products.

(ii) To study the effects of casting temperature on dimensional accuracy of the final part.

(iii) To measure dimensional accuracy (*mm*) using Vernier Calliper.

1.4 BACKGROUND OF THE STUDY

In this study, casting technology called the gravity casting will be used to produce the final part of wax holder. The wax holder will be modelled using solid work. Then polystyrene will be used to produce the master pattern.

The master pattern is then transferred to gravity casting (silicone rubber molding) to create final part product. Finally the dimensional accuracy of the final parts with 3 different temperatures will be measured to find the optimum temperature that has the nearest dimension compare to the pattern.

1.5 PROBLEM STATEMENT

In the casting process, the main problem is the dimension of the final part is not accurate compared to the pattern or drawing. The important of dimensional accuracy in casting is if the product that had been produced in not accurate in dimension, the product will be malfunction and will cause the cost for producing the product increase. This study will investigate the effect of the difference temperature to the dimensional accuracy of the final part compare to the master pattern.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews relevant literatures on producing the product by using gravity casting method. Section 2.2 reviews on the wax holder while section 2.3 reviews on the rapid tooling which gives the theoretical overview of rapid tooling method. There is a review on casting in Section 2.4. Section 2.5 reviews on error in casting, while section 2.6 reviews on paraffin wax. Section 2.7 reviews on paraffin wax and lastly section 2.8 reviews on dimensions and tolerances.

2.2 WAX HOLDER

Wax holder that made from wax is usually use as souvenir. A souvenir is an object a traveler brings home for the memories associated with it.

2.3 RAPID TOOLING

Rapid tooling is an extension of rapid prototyping technology. Rapid prototyping techniques are capable of producing prototypes of very complex part geometry directly from three-dimensional computer aided design (CAD) software in a wide variety of materials such as polymer, wax, and paper without the benefit of specially designed tooling or fixturing. Rapid tooling is enabling art to production of quality parts and accelerating time to market by concentrating on the tool rather than the part (J. William, 1997). Rapid tooling (RT) is a new term that has not yet been clearly defined. It was originally linked to rapid prototyping (RP) but has since been used to define technique and processes that lead to making tools quickly (Peter Hilton, 1995).

Tooling is one of the slowest and most expensive steps in the manufacturing process, because of the extremely high quality required. Tools often have complex geometries, yet must be dimensionally accurate to within a hundredth of a millimeter. In addition, tools must be hard, wear-resistant, and have very low surface roughness (about 0.5 micrometers root mean square). To meet these requirements, molds and dies are traditionally made by CNC-machining, electro-discharge machining, or by hand. All are expensive and time consuming, so manufacturers would like to incorporate rapid prototyping techniques to speed the process. Peter Hilton, president of Technology Strategy Consulting in Concord, MA, believes that "tooling costs and development times can be reduced by 75 percent or more" by using rapid tooling and related technologies (Peter Hilton, 1995).

2.4 CASTING

Casting is a manufacturing process by which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as casting, which is ejected or broken out of the mold to complete the process. Casting materials are usually metals or various cold setting materials that cure after mixing two or more components together; examples are epoxy, concrete, plaster and clay. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other method (Degarmo, E. Paul, 2003; Black, JT, 2003; Kohser, Ronald A., 2003).

2.4.1 Design Advantages of Castings

The need of the designers for objects having certain structural and functional shapes that can withstand stress and strain, fulfill other service condition, possess a desirable appearance and have an acceptable cost is remarkably satisfied by castings (P. L. Jain, 2003). The main design advantages are:

(i) Size: Casting may weigh as much as 200 tons or can be small as a wire of 0.5mm diameter. In fact, casting is the only method available for producing massive objects in one single piece.

(ii) Complexity: The most simple or complex curved surface, inside or outside, and complicated shapes, which would otherwise be very difficult or impossible to machine, forge, or fabricate, can usually be cast.

(iii) Production of Prototypes: The casting process is ideally suited to the production of models or prototypes required for creating new designs.

2.4.2 Advantages of Casting Process

The advantages of casting process are;

(i) Low Cost: Casting is usually found to be the cheapest method of metal shaping.

(ii) Dimensional Accuracy: Castings can be made to fairly close dimensional tolerances by choosing the proper type of moulding and casting process. Tolerances as close as ±0.1mm can be achieved depending on the cast metal, the casting process and the shape and the size of the casting (P. L. Jain, 2003).

2.4.3 Disadvantages of Casting Process

There are disadvantages of casting process (W. Wang, 2004; J. G. Conley, 2004; H. W. Stoll, 2004) such as limitations on mechanical properties and poor dimensional accuracy and surface finish for some processes (for example sand casting).

2.4.4 Gravity Casting

Gravity casting (Sveinn inn kyrri Grimsson, 2004) is a casting process where the molten wax is poured into the mould without application of any external pressure. The molten wax fills up the mould by gravity.

2.5 Error in Casting

During casting the volume of the metal in the mould is constantly changing due to thermal contractions and phase transformations. This volume change can result in non-uniform distortion behavior, or where there are constraints from the mould and the casting itself, stresses are introduced into the casting. Some of these stresses are relieved as a result of creep effects at higher temperatures and some are recovered through springback during mould and gate removal. Residual stresses are captured stresses remaining in the casting and can only be recovered during heat treatments. The residual stresses which are in tension can significantly reduce the fatigue life and corrosion behavior of the casting. Thermal distortions occurring during casting affect the final shape of the component. The ability to predict the shape evolution during gravity casting requires a significant degree of confidence in the mathematical model defining the process and the behavior of the material. The model must accurately simulate all the physical phenomena influencing the shape of the component, thus fully coupling fluid filling, thermal heat transfer as well as all thermo-mechanical interactions (A.P. Paine, 1999; P. Rossouw, 1992; R. Bruwer, 1992; M. William, 1992).

2.5.1 Corners, angles and section thickness

Many casting processes lead to small surface defects (e.g. blisters, scars, scabs or blows), or tiny holes/impurities in the interior (e.g. inclusions, cold-shuts, shrinkage cavities). These defects are a problem if the part with such a defect is subject of varying loads during use. Under such conditions, the defects act like cracks, which propagate under repeated stress causing fatigue failure. Another possibility is that internal holes act as stress concentrators and reduce the actual strength of the part below the expected strength of the design (A.P. Paine, 1999; P. Rossouw, 1992; R. Bruwer, 1992; M. William, 1992). To avoid these problems;

(i) Sharp corners should be avoided (these behave like cracks and cause stress concentration).

(ii) Section changes should be blended smoothly using fillets.

2.5.2 Solidification defect

Solidification defects cold lead to two different manifestations of porosity,localized shrinkage porosity and microporosity. Localised shrinkage porosity is caused by insufficient feeding of the alloy during solidification. As the alloy solidify, it also shrinks by over 1%, and a sufficient supply of molten alloy is required during this phase to counteract reduction in the volume caused by the shrinkage. If the sprue is not properly designed and implemented then it may solidify before the feeding is complete thus preventing a continuous supply of molten alloy. This type of defect usually occurs close to the sprue-casting junction. Microporosity is also caused by solidification shrinkage, but generally happens in fine grain alloys when the solidification is too rapid for the microvoids to segregate (A.P. Paine, 1999; P. Rossouw, 1992; R. Bruwer, 1992; M. William, 1992).

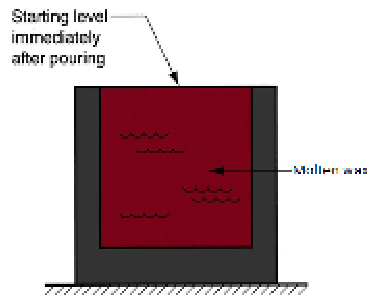

Figure 2.1: Starting Level of Molten Metal Immediately After Pouring

Source: Dieter, 2005

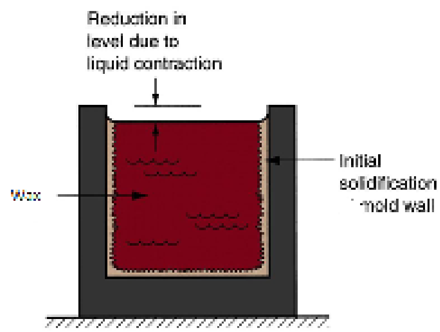

Figure 2.2: Reduction in Level Caused by Liquid Contraction during Cooling

Source: Dieter, 2005

Solidification shrinkage occurs in nearly all metals or wax because the solid phase has a higher density than the liquid phase. Thus, solidification causes a reduction in volume per unit weight of metal (Dieter, 2005).

2.6 SILICONE MOULDING

Silicone moulding compounds offer superior ability to recreate master model detail compared with the others traditional cold synthetic rubber moulding material. There are two advantages of silicone moulding:

(i) Extremely high resolution of master model detail can be copied to the cavity mould.

(ii) Back draft problems (die lock, or the inability to release the part from the mold cavity due to part geometry) are reduced.

2.7 PARAFFIN WAX

Paraffin wax is mostly found as a white, odorless, tasteless, waxy solid, with a typical melting point between about 47 °C to 64 °C (116.6°F to 147.2°F), and having a density of around 0.9 g/cm^3 . It is insoluble in water, but soluble in ether, benzene, and certain esters. Paraffin is unaffected by most common chemical reagents, but burns readily.

Pure paraffin wax is an excellent electrical insulator, with an electrical resistivity of between 10^{13} and 10^{17} ohm metre . This is better than nearly all other materials except some plastics (notably teflon). It is an effective neutron moderator and was used in James Chadwick's 1932 experiments to identify the neutron (Kaye, George William Clarkson, 1995; Laby, Thomas Hewell, 1995).

Paraffin wax ($C_{25}H_{52}$) is an excellent material to store heat, having a specific heat capacity of 2.14–2.9 J g^{-1} K^{-1} (joule per gram per kelvin) and a heat of fusion of 200–220 J g^{-1} (Kaye, George William Clarkson, 1995; Laby, Thomas Hewell, 1995). This property is exploited in modified drywall for home building material: it is infused in the drywall during manufacture so that, when installed, it melts during the day, absorbing heat, and solidifies again at night, releasing the heat. Paraffin wax phase change cooling coupled with retractable radiators was used to cool the electronics of the Lunar Rover (Dean, W. G., 1993; Karu, Z. S., 1993). Wax expands considerably when it melts and this allows its use in thermostats for industrial, domestic and, particularly, automobile purposes (Bodem, Roger, 2001).

In industrial applications, it is often useful to modify the crystal properties of the paraffin wax, typically by adding branching to the existing carbon backbone chain. The modification is usually done with additives, such as EVA copolymers, microcrystalline wax, or forms of polyethylene. The branched properties result in modified paraffin with a higher viscosity, smaller crystalline structure, and modified functional properties. Pure paraffin wax is rarely used for carving original models for casting metal and other materials in the lost wax process, as it is relatively brittle at room temperature and presents the risks of chipping and breakage when worked. Soft and pliable waxes, like beeswax, may be preferred for such sculpture, but "investment casting waxes," often paraffin-based, are expressly formulated for the purpose (Rhodes, Richard, 1986).

2.8 EFFECT OF TEMPERATURE ON DIMENSIONAL ACCURACY

Temperature is one of the factors that affected the dimensional accuracy of casting's product. . Higher pouring temperature causes shrinkage of the casting and mould warping (Grill P. L.,1985).It has been observed (Pius A. P. 2004) that melting and pouring conditions directly or indirectly affects such mechanical properties of cast materials as: hardness, percentage elongation, percentage reduction in diameter, toughness and so on. When pouring temperature is lower than optimum, the mould cavity will not fill the gate or riser will solidify too rapidly and intercept directional solidification (Lancer N.C., 2005).

2.9 DIMENSIONS AND TOLERANCES

In addition to mechanical and physical properties, other factors that determine the performance of a manufactured product include dimensions and tolerances. A dimension is a numerical value expressed in appropriate units of measure and indicated on a drawing and in other documents along with lines, symbols, and notes to define the size or geometric characteristic, or both, of a part or part feature. Dimensions on part drawings represent nominal or basic sizes of the part and its features. The dimension indicates the part size desired by the designer, if the part could be made with no errors or variations in the fabrication process.

A tolerance is "the total amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and minimum limits". Variations occur in any manufacturing processes, which are manifested as variations in part size. Tolerances are used to define the limits of the allowed variation (M. P. Groover, 2002). In this study the tolerance for Mitutoyo vernier caliper is ± 0.03 *mm* (Mitutoyo vernier caliper catalogue).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The methodology used in conducting this experimental study will be discussed in this chapter. It can be divided into five main categories as illustrated in the following figure 3.1. The categories are experiment design, data analysis, study procedures, instrumentation and materials.

3.2 EXPERIMENT DESIGN

In every experimental study, several types of methods can be possibly used in planning, conducting the experiments and analyzing data from the experiments. It is important to understand the objective and the purpose of the research study to ensure the proper data and analysis can be obtained from experimentation. In this study, the main objective is to study the effect of casting temperature to the dimensional accuracy of the final part using gravity casting.

This experimental study is designed with one different parameter of study which is difference temperature. The experiment is conducted by running 3 trials with the wax casting.

The data obtained from the experimentation is then analyzed based on the plotted graph and the depicted table.

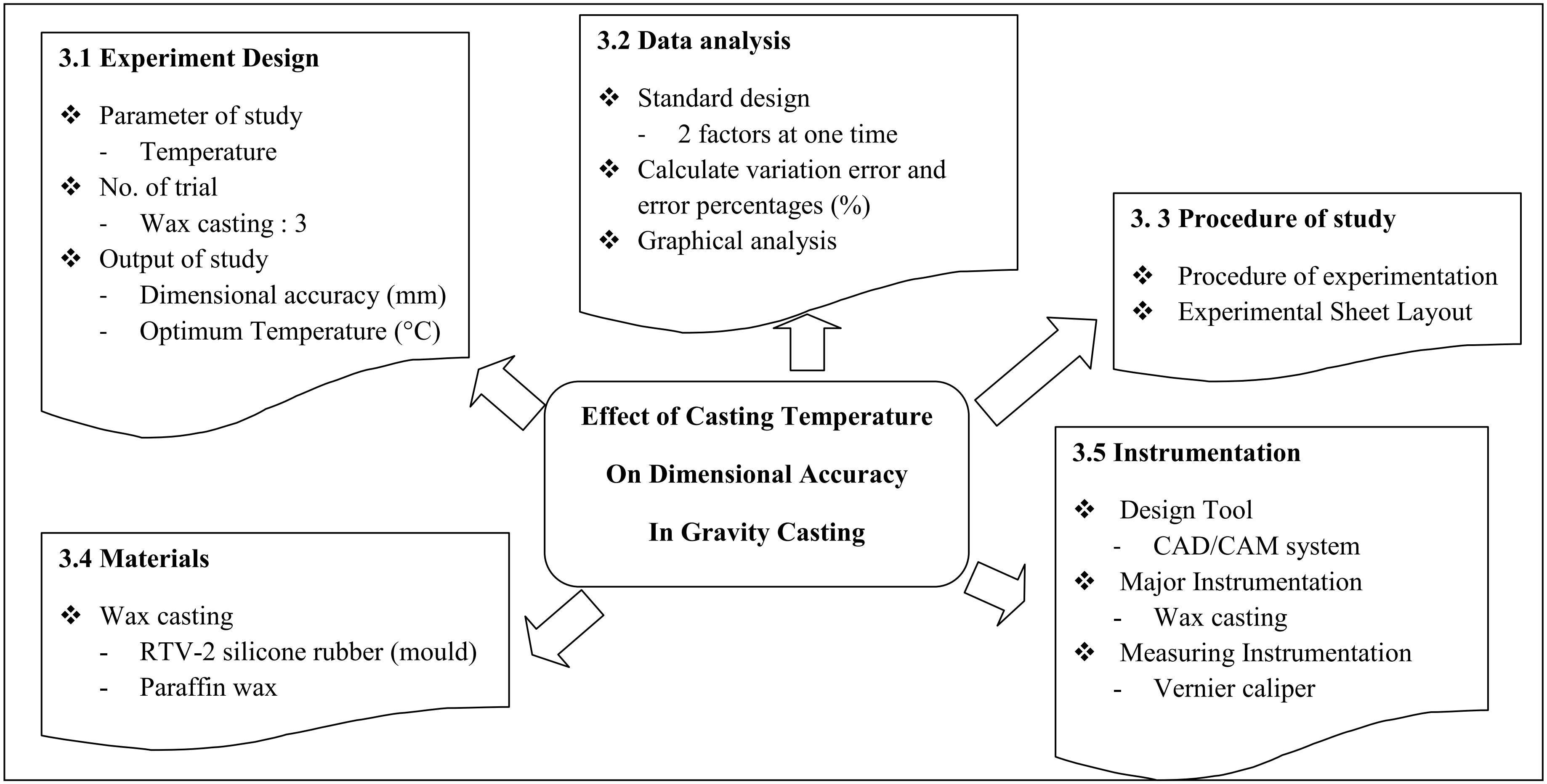

Figure 3.1: Overall Study Methodology

3.3 PARAMETER OF STUDY

The parameter of study is the control factor that has significant influence on the dimensional accuracy of the final part produced by gravity casting. In this study, the undertaken parameter of study is temperature, as shown in Table 3.1.

Table 3.1: Parameter of study

Final Part (Gravity Casting)	**Temperature**		
	47ºC	55ºC	64ºC

3.3.1 Temperature

In this study, 3 different temperatures had been selected. The melting temperature of paraffin wax is between 47ºC to 64ºC. Thus the selected melting temperature would varies from minimum, average and maximum melting temperature which as follows.

(i) 47ºC
(ii) 55ºC
(iii) 64ºC

3.4 NUMBER OF TRIAL

Master patterns and final parts are produced based on the concept as shown in the Figure 3.2.

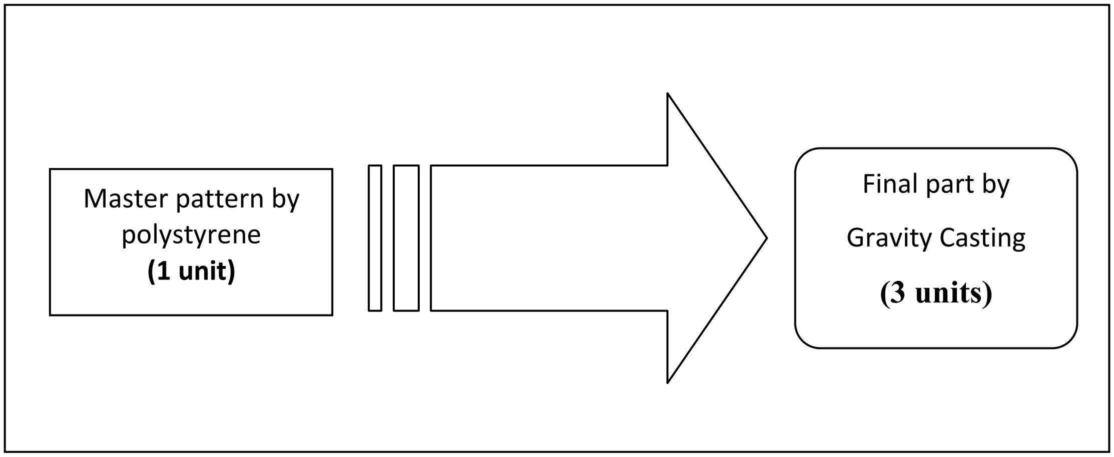

Figure 3.2: Route from Master Pattern to Final Parts

Table 3.2 shows the total number of trial by wax casting depending on different casting temperature. According to Figure 3.2, one master pattern will be using polystyrene. Then 3 final products will be produced using gravity casting.

Table 3.2: Number of Trial by Gravity Casting

Part	**Temperature**		
	47ºC	**55ºC**	**64ºC**
Final part	1 trial	1 trial	1 trial

3.5 OUTPUT OF STUDY

The objectives of the experiment must be clearly and specifically defined. It is because the objectives will represent the goals of this study. In this study, investigation of the effect of casting temperature to the dimensional accuracy of final part by gravity casting is our main objective. Therefore, dimensional accuracy is the main output revealed from this study.

3.5.1 Dimensional Accuracy (*mm*)

Dimensional accuracy of the master pattern and final part will be measured using Vernier Caliper. Dimensions of critical parts will be measured and compared with the actual design. Critical parts for the actual design of wax holder are indicated in Figure 3.3, 3.4, 3.5 and Figure 3.6. These critical parts are chosen based on their significance in ensuring the functionality of the new wax holder. The analysis of dimensional accuracy for those critical parts and the comparison with the actual design among the master patterns are made in order to choose the best master pattern for mould production. The selection is based on the total less error concept where the total of error for every critical part in each different setting of parameter is made and the master pattern with the less total of error will be chosen. The comparison of the final part with the actual design is made to justify the credibility of rapid tooling application in producing the wax holder in terms of its dimensional accuracy.

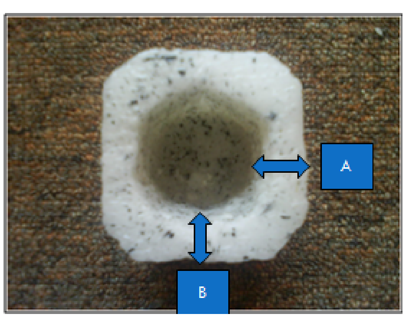

Figure 3.3: Critical Part: Part A and B

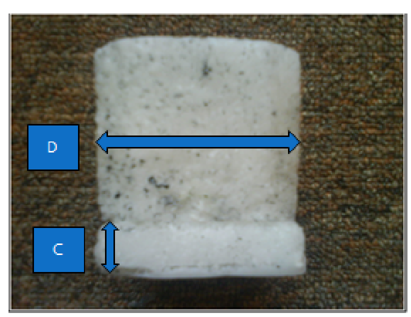

Figure 3.4: Critical Part: Part D and C

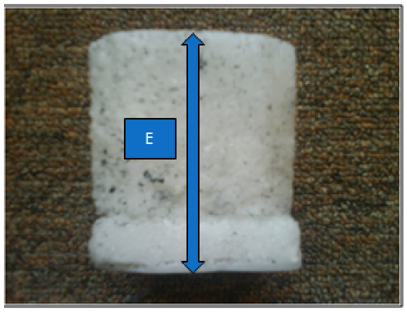

Figure 3.5: Critical Part: Part E

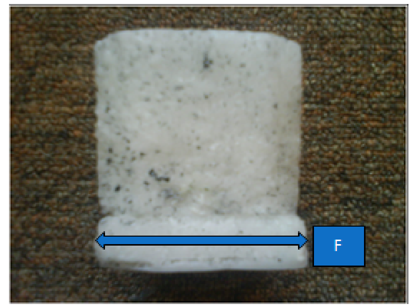

Figure 3.6: Critical Part: Part F

3.5.2 Casting Temperature

In this study the effect of temperature to the dimensional accuracy of the final part will be analyzed. Three different temperatures will be used that are minimum, average and maximum melting temperature of the paraffin wax.

3.6 DATA ANALYSIS

The data obtained in this experimental study is analyzed using standard design method. It consists of one factor at one time. This type of approach is used in this study to enable the analysis of data obtained from the set up parameters. The particular factor, which is temperature, is the only one factor used at one time, during each experiment.

3.6.1 Variation and Error Values

The analysis of dimensional accuracy is done by determining the variation and error value of each measured parts. Equation 3.1 and 3.2 below represent the formulas used in this experimental data analysis;

(i) Variation

$$\text{Var.} = ActualDimension - MeasuredDimension \qquad (3.1)$$

(ii) Percentage of error (%)

$$\%\ \text{error} = \frac{ActualDimension - MeasuredDimension}{ActualDimension} \times 100 \qquad (3.2)$$

3.6.2 Graphical analysis

The analysis of dimensional accuracy is conducted by using graphical analysis. For the dimensional accuracy the variation and percentage of error are plotted as bar graph, based on the obtained data. The findings are analyzed from the plotted graph, for example as shown in Figure 3.7.

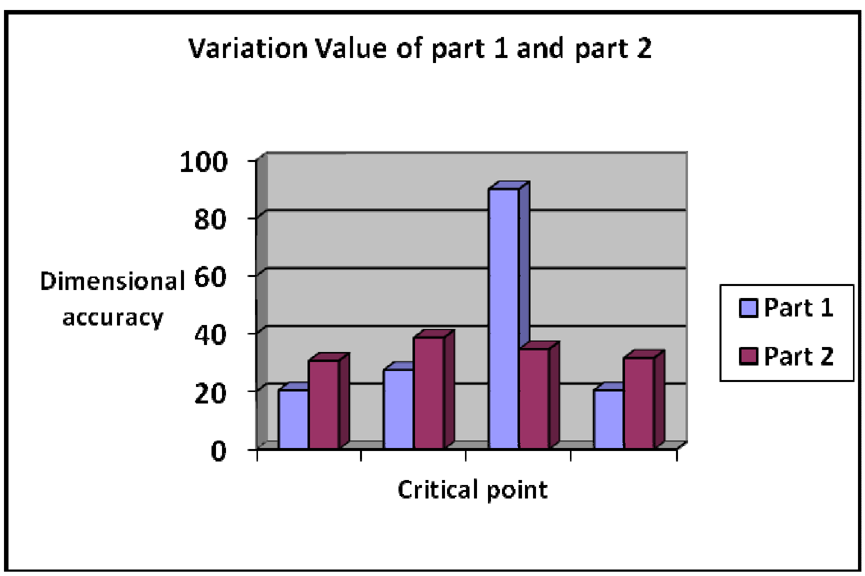

Figure 3.7: Example of Plotted Graph for Dimensional Measurement

3.7 PROCEDURE OF THE STUDY

Study procedures are an important element in conducting this study. The experimental procedure will be discussed in the following section.

3.7.1 Experimental Procedure

Experimental procedure is an overall explanation about the sequence of work done in producing the final part, starting from the design phase until the production of the final part. The details procedure can be referred in Figure 3.8

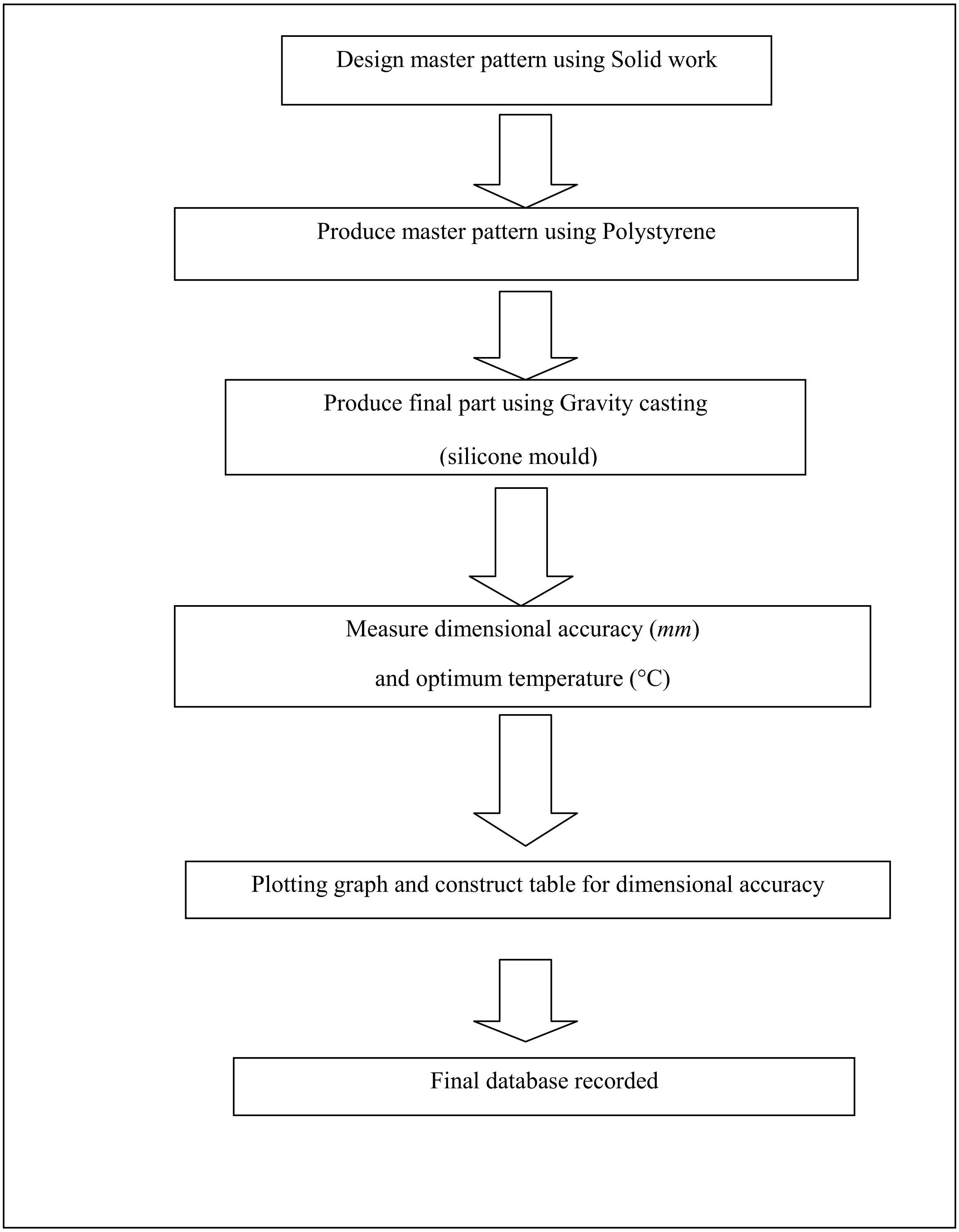

Figure 3.8: The Experimental Procedure

3.8 MATERIALS

Several types of material are selected to produce silicone moulding and final part by gravity casting. In this study the material for silicone moulding, and gravity casting are Room Temperature Vulcanizing-2 (RTV-2) silicone rubber and paraffin wax.

3.8.1 Silicone Rubber Moulding (Mould Part)

For silicone moulding, the material used to produce the mould is silicone type RTV-2 silicone rubber. The properties of this material are as shown in Table 3.3.

Table 3.3: Properties of RTV-2 Silicone Rubber

Material Properties	
Appearance	white
Viscosity (cs)	14000-16000
Melting Point	350 - 400˚ C
Specific gravity	1.10±0.03
Durometer hardness	32
Tensile strength	22.0 N/mm^2
Tear strength	> 24 N/mm
Elongation	450%
Shrinkage	< 0.5%
Working time	10 ~ 30 min
Skin over time	30 ~ 60 min
Curing time	24 hr

Source: RTV-2 silicone rubber for moldmaking catalogue

3.8.2 Gravity Casting (Final Part)

For gravity casting the material used to produce the final parts is paraffin wax. The material properties of paraffin wax are as shown in table 3.4.

Table 3.4: Properties of Paraffin Wax

Material Properties	
Melting point	47ºC - 64ºC
Density	0.9 g/cm³
Specific heat capacity	2.14 – 2.9 Jg
Electrical resistivity	10^{13} and 10^{17} ohm metre
Specific heat capacity	2.14–2.9 J g^{-1} K^{-1}
Heat of fusion	200–220 J g^{-1}

Source: Kaye 1995

3.9 INSTRUMENTATION

There are several instrumentations used to conduct this study. This study's instrumentation consist of design software to create 3-D model, major instrumentation to fabricate master patterns and finished parts, and lastly measuring instrumentation to inspect dimension (*mm*) and optimum temperature (ºC)

3.10 DESIGN TOOLS

Designing tool is an important element in the design stage. CAD helps the designers prepare drawings, specifications, parts lists, and other design related elements using special graphics and calculations intensive computer programs. Although CAD systems originally merely automated drafting, CAD now usually includes three-dimensional modeling and computer-simulated operation of the model. The CAD system used in this study is the Solid Work.

3.11 MAJOR INSTRUMENTATION

In this study, one major instrument is used, which gravity casting. Gravity casting is used to produce the finished part.

3.11.1 Gravity Casting

In this study, gravity casting with silicone moulding is applied to produce the final parts based on the selected master pattern. Figure 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16, 3.17 and 3.18 shows the process that involve in gravity casting. The first step in gravity casting is producing the mould. Figure 3.9, 3.10, 3.11, 3.12, 3.13 and 3.14 show the process to produce the mould.

The pattern is placed within a frame and it is secure to the bottom as shown in Figure 3.9.

Figure 3.9: Place the master pattern in a box

The RTV-2 silicone rubber is poured into the mould until the master pattern is completely covered and secondary de-arising is carried out to eliminate all bubbles from the RTV-2 silicone rubber. The brush is used to spread the RTV-2 silicone rubber uniformly over the surface of the master pattern first the brush is used until all air pockets on the surface have been removed and the rest of the RTV-2 silicone rubber is poured into the mould.

Figure 3.10: Curing agent

Figure 3.11: RTV-2 silicone rubber

Required amounts of silicone rubber and curing agent are weight out and it is mixed together. The amount of silicone rubber is 10:1 to the amount of curing agent.

Figure 3.12: Pour in RTV-2 silicone rubber

The RTV-2 silicone rubber is poured approximately up to 1cm from the top of the master pattern and the top cover is placed on the frame and let the mould stand.

Figure 3.13: Removed the bottom cover

The bottom cover is removed after the wax fully solidified and master pattern is taken out.

Figure 3.14: Take out master pattern

The wax is heated until the wax completely become liquid then the temperature of the wax is measured using IR thermometer.

Figure 3.15: Heat the wax

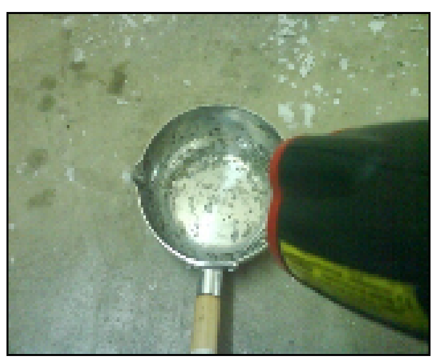

Figure 3.16: Measure the temperature

Finally the wax is poured into the silicone rubber mold and let it cure. After the wax is totally solidified then the product is taken out.

Figure 3.17: Pour in the wax

Figure 3.18: Let it cure

3.12 MEASURING INSTRUMENT

In this experimental study, two types of measuring instrument are used. Types of measuring instrument in this study are:

(i) Vernier Caliper
(ii) Infrared Thermomether.

3.12.1Vernier Caliper

A vernier caliper consists of a high quality metal ruler with a special vernier scale attached which allows the ruler to be read with greater precision than would otherwise be possible. The vernier scale provides a means of making measurements of distance (or length) to an accuracy of a tenth of a millimeter or better.

A vernier caliper is used to precisely measure dimensions to within thousandths of a centimeter. A vernier scale can be incorporated into any measurement device that has a measurement scale. It allows the user to determine the measurement on the device to within a sub-division of the main scale. The tolerance indicates the permissible inaccuracy or error in manufacturing of the part which allow it to serve as duplicate for original. The tolerance of vernier caliper for this study is ±0.03*mm* (Mitutoyo Vernier Caliper Catalogue).

Figure 3.19: Vernier caliper

3.12.2 Infrared Thermometer.

Infrared (IR) thermometers use infrared technology to quickly and conveniently measure the surface temperature of objects. IR thermometer provides fast temperature readings without physically touching the object. Lightweight, compact, and easy-to-use, IR thermometers can safely measure hot, hazardous, or hard-to-reach surfaces without contaminating or damaging the object. Also, infrared thermometers can provide several readings per second, as compared to contact methods where each measurement can take several minutes.

Figure 3.20: Infrared thermometer

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter reviews the findings and data analysis of this experimental study. In this study, all the final products from the gravity casting process are subjected to the dimensional accuracy analysis. The results of dimensional accuracy of final parts from the silicone moulding are included. The measurement is conducted three times to ensure precision and accuracy. Graphs are plotted for every analysis done to visualize the difference.

4.2 DIMENSIONAL ACCURACY (*mm*) OF GRAVITY CASTING

This section reviews the findings on the dimensional accuracy of all the final products produced by wax casting.

4.2.1 Tables and Graphical Analysis

Table 4.1 and 4.2 depict the results obtained from the measurement of the final product's dimensional accuracy by using Vernier Calliper. The data is analyzed by using graphical method to select final products which has the best dimensional accuracy. The analysis is also conducted to determine the values of mean, variation and the percentage of error of the final products.

There are six critical points measured for every part, where the measurements are conducted three times each to ensure precision. Thus, there are eighteen measurements conducted for each part which later being averaged according to the six critical points.

Table 4.1: Dimensional Accuracy (mm) Data for Gravity Casting

Temperature (^oC)	**Part**	**Dimension (±0.03*mm*)**					
		A	**B**	**C**	**D**	**E**	**F**
47 ^oC	**1**	9.97	9.97	9.96	59.98	59.98	59.98
	2	9.95	9.97	9.96	59.96	59.96	59.98
	3	9.96	9.97	9.96	59.97	59.97	59.98
	Mean	9.96	9.97	9.96	59.97	59.97	59.98
55 ^oC	**1**	9.97	9.96	9.97	59.97	59.98	59.98
	2	9.97	9.98	9.99	59.99	59.96	59.98
	3	9.97	9.97	9.98	59.98	59.97	59.98
	Mean	9.97	9.97	9.98	59.98	59.97	59.98
64 ^oC	**1**	9.93	9.97	9.95	59.98	59.96	59.97
	2	9.95	9.95	9.97	59.98	59.96	59.95
	3	9.94	9.96	9.96	59.98	59.96	59.96
	Mean	9.94	9.96	9.96	59.98	59.96	59.96

Table 4.2: Variation and Percentages of Error

Temperature (°C)	Part	Dimension (±0.03*mm*)					
		A	**B**	**C**	**D**	**E**	**F**
47 °C	**Actual**	**10**	**10**	**10**	**60**	**60**	**60**
	Mean	9.96	9.97	9.96	59.97	59.97	59.98
	Var	0.04	0.03	0.04	0.03	0.03	0.02
	% Error	0.40	0.30	0.40	0.30	0.30	0.20
55 °C	**Actual**	**10**	**10**	**10**	**60**	**60**	**60**
	Mean	9.97	9.97	9.98	59.98	59.97	59.98
	Var	0.03	0.03	0.02	0.02	0.03	0.02
	% Error	0.30	0.30	0.20	0.20	0.30	0.20
64 °C	**Actual**	**10**	**10**	**10**	**60**	**60**	**60**
	Mean	9.94	9.96	9.96	59.98	59.96	59.96
	Var	0.06	0.04	0.04	0.02	0.04	0.04
	% Error	0.60	0.40	0.40	0.20	0.40	0.40

(i) Calculation of Mean value

The calculation of Mean value of the dimension is based on:

$$Mean = \frac{Trial1 + Trial2 + Trial3}{2} \tag{4.1}$$

For example from result data sheet, Part A at temperature 47°C;

$$Mean = \frac{Trial1 + Trial2 + Trial3}{2} = \frac{(9.97) + (9.95) + (9.96)}{2} = 9.96\ \pm 0.02mm$$

(ii) Calculation of Variation Value

The calculation of Variation value of dimension is based on:

$$Var. = \left| ActualDimension - MeanDimension \right| \tag{4.2}$$

For example from Mean value of Part A at temperature 47°C:

$$Var. = \left|10.00 - 9.96\right| = \left|0.04\right| = \underline{\underline{0.04}}$$

(iii) Calculation of Error Percentage (%)

The calculation of Error Percentage (%) of the measurement is based on:

$$Error\% = \frac{ActualDimension - MeanDimension}{ActualDimension} \times 100 \tag{4.3}$$

For example from Mean value of Part A at temperature 47°C:

$$Error\% = \frac{ActualDimension - MeanDimension}{ActualDimension} \times 100$$

$$= \frac{Var.}{ActualDimension} \times 100$$

$$= \frac{0.04}{10.00} \times 100 = \underline{\underline{0.4}}$$

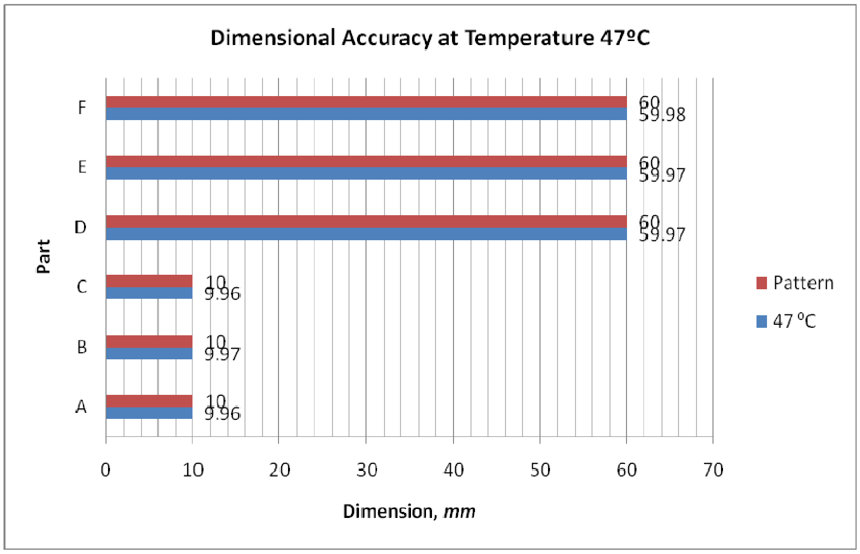

Figure 4.1: Dimensional Accuracy at Temperature 47°C

Figure 4.1 depicts the result of the measurement from the final product at temperature 47ºC. Part A and C have the largest differences in dimension compare to the actual dimension. At this temperature Part F has the nearest dimension compare to the actual dimension. Further discussion about this result will be discussed in section 4.3.

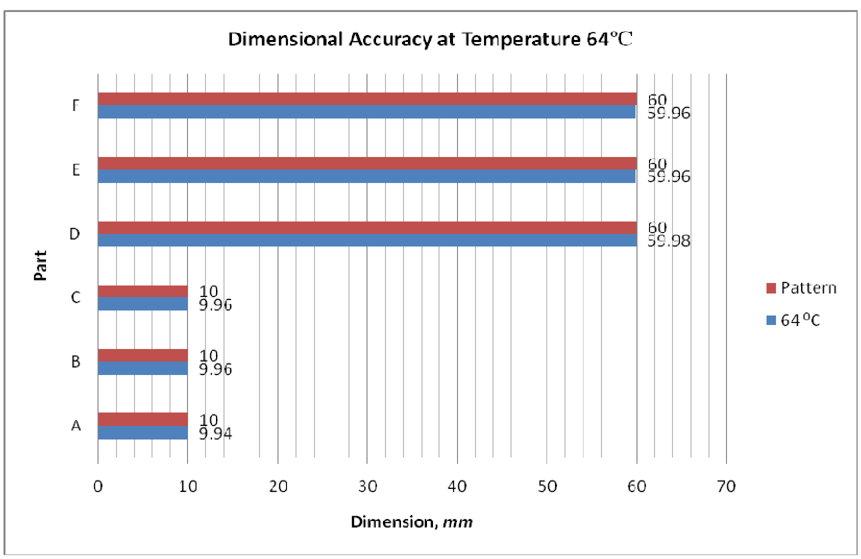

Figure 4.2: Dimensional Accuracy at Temperature 55°C

Figure 4.2 depicts the graphical analysis on the final product at temperature 55°C as compared to the actual data. From the figure, it is clearly shown that the dimension F, D, and C are actually close to the actual data value while dimension A, B and E are smaller than the other part. Further discussion about this result will be discussed in section 4.3.

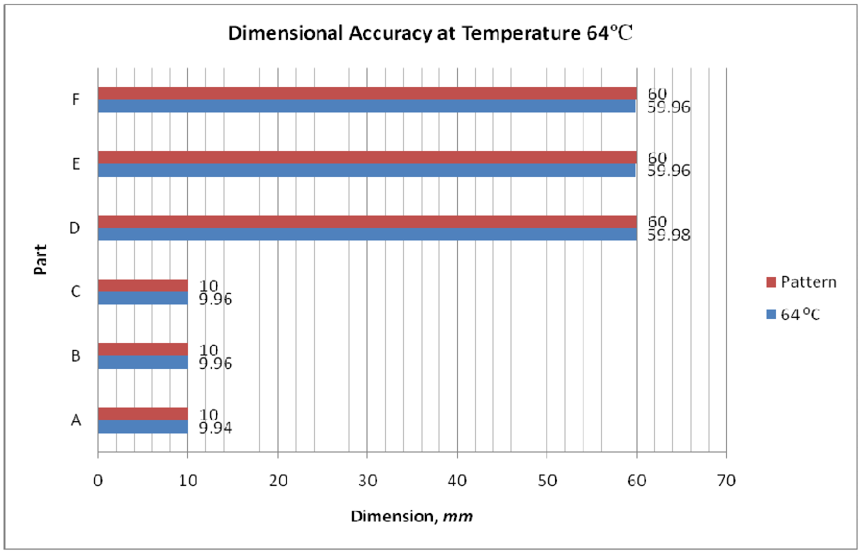

Figure 4.3: Dimensional Accuracy at Temperature 64°C.

Figure 4.3 shows the graphical comparison of dimensional accuracy between final product at temperature 64°C and pattern (actual). From the figure, it shows that the final part dimensions for Part A has the largest difference compare to the other parts, while B, C, E and F are lesser as compared to the actual part.

From Figure 4.1, 4.2 and 4.3 the bar graph of dimensional accuracy of final products shows that the values of critical points from the final products are not equally the same as the critical points from the actual part. Occasionally, the values decrease due to the different temperature that is applied to the casting.

It is difficult to determine which final products have the nearest value to the actual part by referring only to this particular graph. Further discussion about this result will be discussed in section 4.3.

4.3 VARIATION AND PERCENTAGES OF ERROR

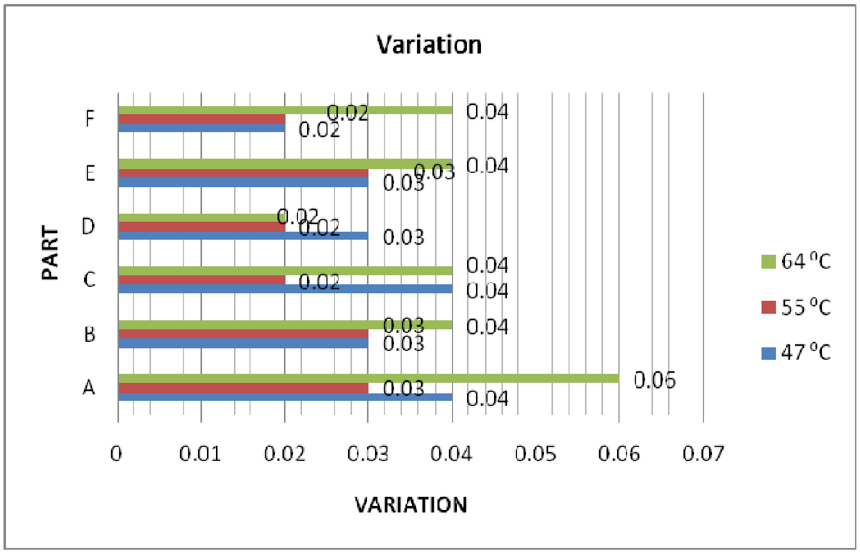

Figure 4.4: Variation

From Figure 4.4, it shows that the highest variation is at Part A at temperature 64°C, while the lowest variation are at Part C at temperature 55°C, Part D at temperature 55°C and 47°C, and Part F at temperature 47°C and 55°C. Part D shows the lowest variation among the other part. Further discussion about this result will be discussed in next graph.

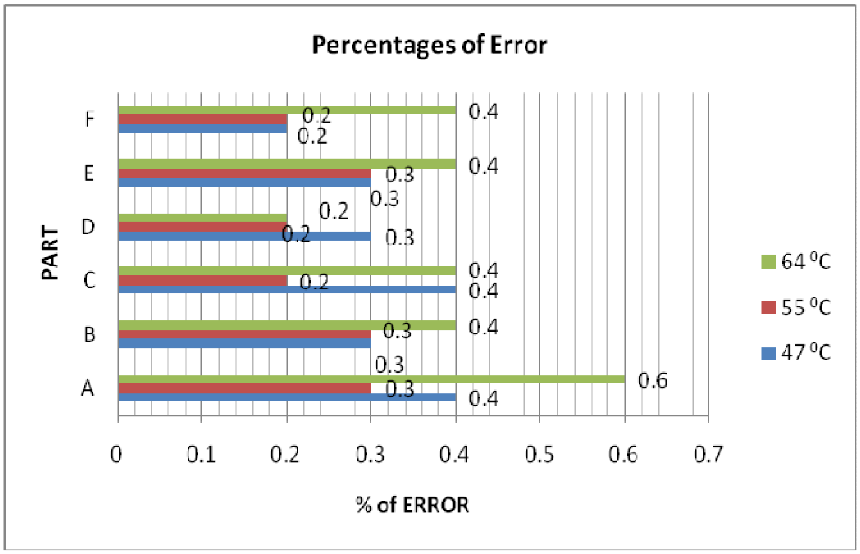

Figure 4.5: Percentages of Error

From Figure 4.5, it shows the percentage of error for all parts at temperature 47^{0}C, 55^{0}C and 64^{0}C. Final product at temperature 55^{0}C has the smallest percentages of error compare to the other final products. At temperature 55^{0}C the highest percentage of error of final product is 0.3 and the smallest percentages of error is 0.2. At temperature 47^{0}C the highest percentages of error is 0.4 and the smallest percentages of error is 0.2. At temperature 64^{0}C the highest percentage of error of final product at this temperature is 0.6 and the smallest percentages of error is 0.2.

Based on the total less error concept as indicated in Table 4.5, it shows that temperature 55°C has better dimensional accuracy (*mm*) as compared to other melting temperatures. This possible variation is mainly due to the thermal conductivity of the mould materials. In general, a higher casting temperature may cause more shrinkage than a lower casting temperature.

It has been identified that cavity filling and solidification process are two most critical aspects to produce premium quality casting components. During the solidification process of casting process, it is a well known phenomenon that metal experiences volumetric shrinkage due to its density difference between liquid and solid phase. When this volumetric shrinkage is not properly compensated, then a casting defect commonly known as solidification shrinkage occurs. The solidification shrinkage has very detrimental effects on structural integrity required for premium quality casting. Literature and practical experiences of foundry men show that it is critical to achieve unidirectional solidification pattern by avoiding an isolated hot spot in order to minimize the solidification shrinkage (Zhan C, 2008).

The shrinkage of metal casting from solidification temperature to room temperature also affects the dimensions of the final casting (D. K. Pal.et al., 2004). It has been stated (Lancer N.C., 2005) that when pouring temperature is lower than optimum, the mould cavity will not fill the gate or riser will solidify too rapidly and intercept directional solidification. At temperature 47°C, the molten wax in the mould solidify too rapidly and this will cause shrinkage problem. This problem will affect the dimensional accuracy of the final product. Same problem occur when using temperature 55°C and 64°C, the solidification shrinkage problem had affected dimensional accuracy of the final products.

At temperature 64°C, the wax is already mixed with the gas because when the temperature is increase the bond between molecules of the material will become weak. This problem will cause the molten wax in the mould vaporize and affected dimensional accuracy of the final product. That why the product at temperature 64°C resulted highest in percentages of error and variation comparing with the other final products. Higher pouring temperature causes shrinkage of the casting and mould warping (Grill P. L.,1985).It has been observed (Pius A. P. 2004) that melting and pouring conditions directly or indirectly affects such mechanical properties of cast materials as: hardness, percentage elongation, percentage reduction in diameter, toughness and so on. The optimum pouring speed is also found to be a function of the casting size and shape. The conditions such as the temperature surrounding and poring speed had been neglected in this study.

4.4 SELECTION OF THE BEST FINAL PRODUCT

From the analysis of the obtained results, the best final product is determined based on the dimensional accuracy of the final product compared to the pattern. As discussed in Section 4.1, final product at temperature of 55°C has the best dimensional accuracy compared to the other 2 final products. Based on discussion and analysis in section 4.2 final product at temperature 55°C has the lowest percentages of error and variation among other final products. Therefore, final product at temperature 55°C is declared to have the best dimensional accuracy among others, thus the optimum temperature to produce the product that have the best dimensional accuracy for this study is 55°C.

Figure 4.6: Final Product at Temperature 55°C

Figure 4.7: Final Product at Temperature 55^{o}C

Figure 4.8: Final Product at Temperature 64^{o}C

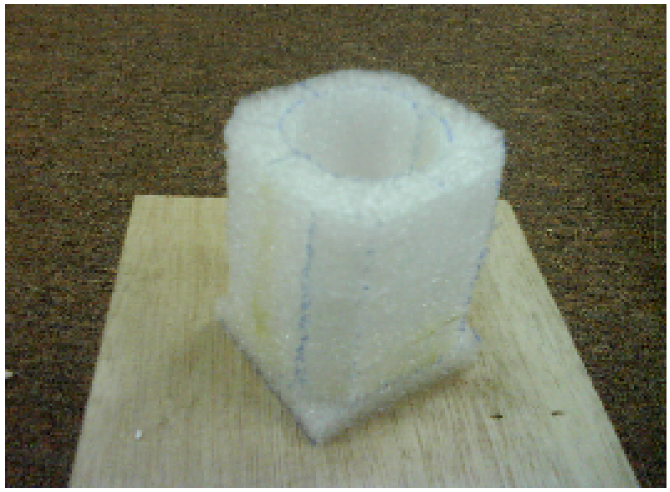

Figure 4.9: Pattern

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 INTRODUCTION

This chapter reviews overall conclusions which are based on the analysis of findings shown in the previous chapter. Section 5.2 discusses on the summary of the experimental study while conclusions are discussed in section 5.3. Suggestions for future study are included in section 5.4.

5.2 SUMMARY

This experimental study is carried out based on the standard analysis approach known as one factor at one time. The master pattern from polystyrene is used for mould production. Finally, the mould will be used in the gravity casting for producing the final parts. The parts are analyzed in terms of dimensional accuracy *(mm)* in order to get the comparison dimensional accuracy between the final products and in order to get the closest and nearest value of dimensional accuracy as compared to the pattern. The analyses applied in this study are mathematical and graphical analysis.

5.3 CONCLUSION

This section reviews the conclusion drawn from this experimental study. The conclusions are below.

(i) The final product at temperature 55°C has the lowest variation and percentages of error among the other final products.

(ii) The final product at temperature 55°C resulted in better dimensional accuracy (*mm*) rather than final product at temperature 47 °C and 64 °C.

(iii) The optimum temperature for gravity casting process in this study is 55°C.

5.4 RECOMMENDATIONS FOR FUTURE STUDY

There are many drawbacks in this experimental study which contributed to the errors in values and results obtained. Considering weaknesses experienced through this study, some recommendations are made which are as follows:

(i) Include other parameter settings in this study such as the time taken for the wax to fully solidify.

(ii) Produce the pattern using 3D-printing with different layer thickness and build orientation.

(iii) The number of dimensions for dimensional accuracy (mm) measurement should be increased to ensure the accurate data will be obtained.

(iv) Measure and comparing the surface roughness between final products and pattern.

(v) Comparing the strength, hardness and microstructure between final products.

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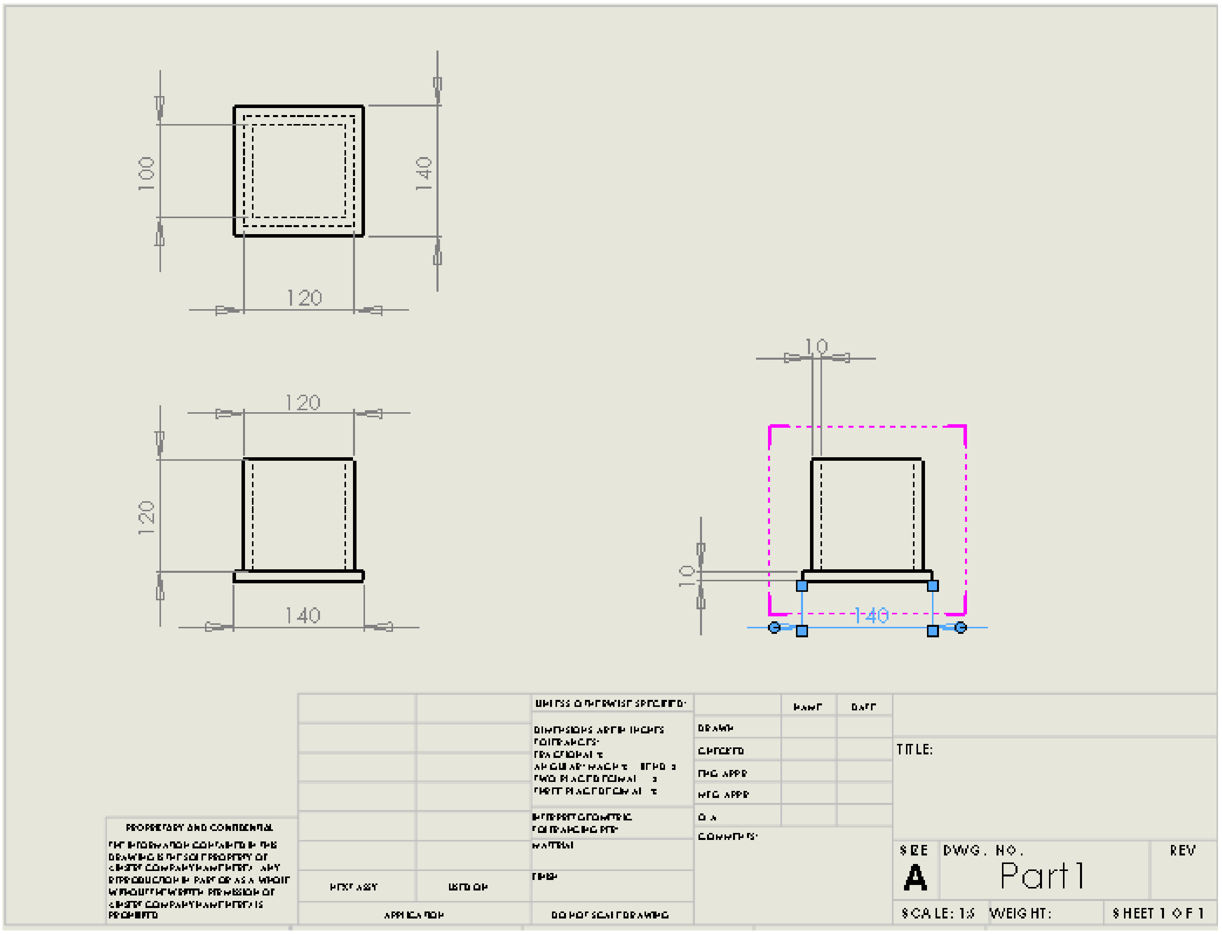
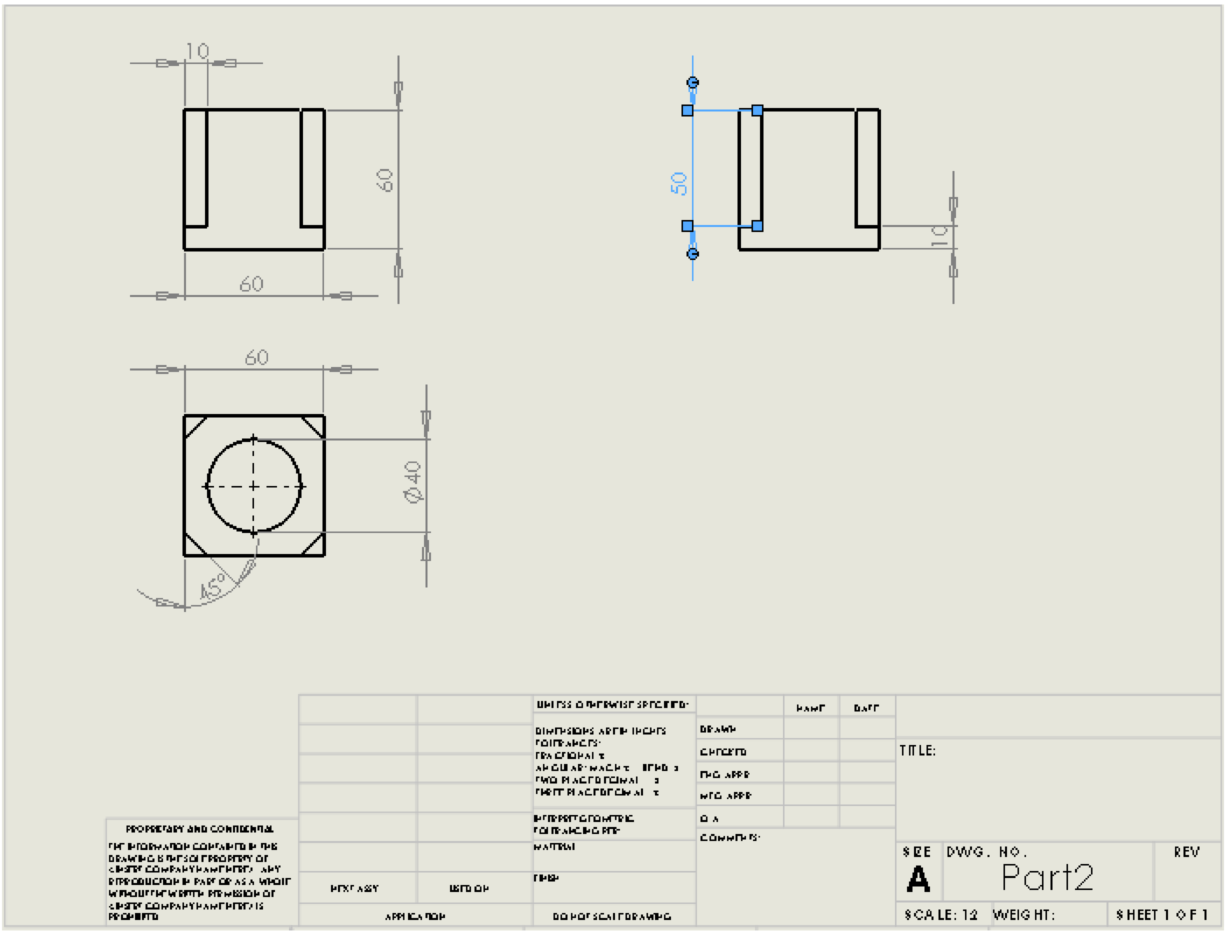
APPENDIX A

ENGINEERING DRAWING FOR BOX MOULD



APPENDIX B

ENGINEERING DRAWING FOR PATTERN



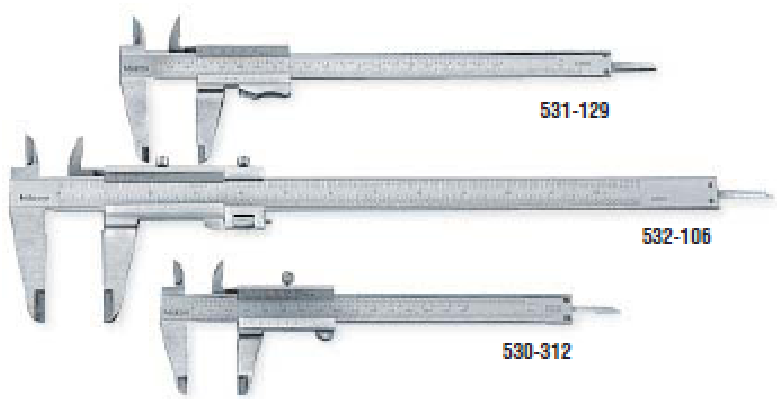
APPENDIX C

MITUTOYO VERNIER CALLIPER CATALOGUE

CALIPERS

Precision Vernier Calipers

Series 530, 531, 532



Features

- The finest of vernier calipers for accurate work, with Mitutoyo's exclusive "Quadri" 4-way measuring feature.
- Can measure OD, ID, depth and steps.
- Models available with a fine-adjustment carriage to fine-feed the slider.

Specifications

Vernier Caliper (with Fine Adjustment)

Inch

	Range		Vernier Resolution		
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy
532-104	0–5"	0–5"	.001"	1/128"	±.0015"
532-106	0–7"	0–7"	.001"	1/128"	±.0015
532-108	0–11"	0–11"	.001"	1/128"	±.0015"

Inch/Metric

	Range		Vernier Resolution		
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy
532-119	0–130mm	0–5"	0.02mm	.001"	±0.03mm
532-120	0–180mm	0–7"	0.02mm	.001"	±0.03mm
532-121	0–280mm	0–11"	0.02mm	.001"	±0.04mm

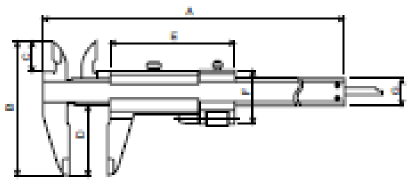
Mitutoyo

CALIPERS

Dimensions (Fine Adjustment Type)

Order No.	A	B	C	D	E	F	G	t●
532-104 532-119	9.02"	3.05"	.65"	1.58"	3.0"	1.23"	.63"	.118"
532-105 532-120	11.34"	3.58"	.81"	1.97"				
532-106 532-121	15.67"	4.39"	.87"	2.52"	3.66"	1.5"	.79"	.150"

● t : Jaw Thickness



Vernier Calipers

Inch

	Range		Vernier Resolution			
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy	Remarks
530-105	0–6"	0–6"	.001"	1/128"	±.0015"	
530-314	0–6"	0–6"	.001"	1/128"	±.0015"	with OD Carbide Jaw
530-116	0–8"	0–8"	.001"	1/128"	±.0015"	

Inch/Metric

	Range		Vernier Resolution			
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy	Remarks
530-104	0–150mm	0–6"	0.05mm	1/128"	±0.05mm	
530-312	0–150mm	0–6"	0.02mm	.001"	±0.03mm	
530-118	0–200mm	0–8"	0.02mm	.001"	±0.03mm	
530-115	0–300mm	0–12"	0.05mm	1/128"	±0.08mm	
530-119	0–300mm	0–12"	0.02mm	.001"	±0.04mm	
530-101	0–150mm	—	0.05mm	—	±0.05mm	
530-108	0–200mm	—	0.05mm	—	±0.05mm	
530-321	0–200mm	—	0.05mm	—	±0.05mm	with OD Carbide Jaw
530-109	0–300mm	—	0.05mm	—	±0.08mm	
530-322	0–300mm	—	0.05mm	—	±0.08mm	with OD Carbide Jaw
530-501	0–600mm	—	0.05mm	—	±0.10mm	

Vernier Caliper (with Thumb Clamp)

Inch

	Range		Vernier Resolution		
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy
531-113	0–6"	0–6"	.001"	1/128"	±.0015"
531-114	0–8"	0–8"	.001"	1/128"	±.0015"

Inch/Metric

	Range		Vernier Resolution		
Order No.	Lower scale	Upper scale	Lower scale	Upper scale	Accuracy
531-107	0–150mm	0–6"	0.05mm	1/128"	±0.05mm
531-128	0–150mm	0–6"	0.02mm	.001"	±0.03mm
531-108	0–200mm	0–8"	0.05mm	1/128"	±0.05mm
531-129	0–200mm	0–8"	0.02mm	.001"	±0.03mm

APPENDIX D

GANTT CHART FOR FINAL YEAR PROJECT 1

Project Progress		W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14
1) Get the project title and arrange discussion time with supervisor	Planning														
	Actual														
2) Built the basic knowledge about the project (learning the theory)	Planning														
	Actual														
3) Do research and collect the information from various resources	Planning														
	Actual														
4) State the objective, scope and importance of the study (chapter I)	Planning														
	Actual														
5) Review study on Rapid Prototyping journals and thesis (chapter II)	Planning														
	Actual														
6) Study of Rapid Prototyping principles and applications (chapter II)	Planning														
	Actual														
7) State the overview of the experiment's procedures (chapter III)	Planning														
	Actual														
8) Provide the expected result based on previous research (chapter III)	Planning														
	Actual														
9) Submit draft thesis and log book for final year project 1	Planning														
	Actual														
10) Final year project 1 presentation	Planning														
	Actual														

APPENDIX E

GANTT CHART FOR FINAL YEAR PROJECT 2

Project Progress		W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16
1) Materials and tool preparation	Planning																
	Actual																
2) Producing the master pattern using polystyrene	Planning																
	Actual																
3) Producing the silicone mold and producing the final part	Planning																
	Actual																
4) 4)Measuring the dimensional accuracy of final parts	Planning																
	Actual																
5) Discuss the analyzed results	Planning																
	Actual																
6) Make conclusion and provide suggestion for improvement	Planning																
	Actual																
7) Preparation for final year project 2 presentation	Planning																
	Actual																
8) Final year project 2 presentation	Planning																
	Actual																
9) Prepare the proper thesis to submit	Planning																
	Actual																