DESIGN AND ANALYSIS OF PRESSING MECHANISM FOR IMROVING 3D PRINTING PROCESS

MUHAMMAD HAFIZ HELMI BIN IBRAHIM

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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MUHAMMAD HAFIZ HELMI BIN IBRAHIM

A report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "Design and Analysis of Pressing Mechanism For Improving 3D Printing Process" is the result of my own work except as cited in the references

Signature : ....

Name : Muhammad Hafiz Helmi Bin Ibrahim

Date : ....

PENGAKUAN

Saya akui laporan ini yang bertajuk “Reka Bentuk dan Analisis Mekanisme Menekan Untuk Memperbaiki Proses Percetakan 3D” adalah hasil kerja saya sendiri kecuali yang dipetik daripada sumber rujukan.

Tandatangan : ....

Nama : Muhammad Hafiz Helmi Bin Ibrahim

Tarikh : ....

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.

Signature : ....

Supervisor's Name : Associate Professor Ir. Dr. Mohd Rizal bin Alkahari

Date : ....

DEDICATION

To Allah S.W.T

For blessing me with a wonderful life

To my beloved mother

A strong and gentle soul who taught me to believe in hard work

To my father

For always supporting me and encouraging me not to give up in life

To my peers

For always cheer me up

ABSTRACT

Three-dimensional printing is a method in which a digital model is transformed into physical object by adding material layer by layer. Despite rapid progress of 3D printing, there are still several area that can still be improve. In 3D printed object, there are many porous areas because of the circular shape of the printed filament. As amount of porous increase, the strength of the printed object decrease. The purpose of this paper is to design new pressing mechanism that act as an attachment to the existing 3D printer and to analyse the effectiveness of the developed system. The selection for the pressing mechanism was made using morphological chart. The prototype for this mechanism was integrated to the existing Fused Deposition Modeling (FDM) 3D printer to apply pressure during printing process. For the pressing mechanism to be tested, a dog bone sample was printed to use for the experiment. Original dog bone samples are compared to the sample with pressure applied on it. Infill density and printing speed are the parameter chosen to be tested. Through the length, width, thickness, surface roughness test, tensile test, and porosity test, the mechanical properties and the dimension of parts fabricated by the new mechanism were obtained. Results show that sample with pressure for infill density parameter were better compared to original sample. As for the speed parameter, sample with pressure applied did improved the porosity percentage of the sample but only at lower printing speed. The pressing mechanism does help improved the strength of the printed object but at the cost of sacrificing the actual dimension of the samples.

ABSTRAK

Pencetakan tiga dimensi adalah satu kaedah di mana model digital diubah menjadi objek fizikal dengan cara menambah bahan lapisan demi lapisan. Walaupun proses pencetakan 3D mengalami kemajuan yang pesat, masih ada yang boleh diperbaiki. Dalam objek cetakan 3D, terdapat banyak liang-liang disebabkan oleh bentuk bulat filament. Apabila kawasan berliang meningkat, kekuatan objek yang dicetak menurun. Kajian ini bertujuan untuk mencipta mekanisme penekan baharu yng bertindak sebagai bahagian tambahan kepada pencetak 3D sedia ada dan bertujuan untuk menganalisis keberkesanan sistem yang dibangunkan. Cara pemilihan reka bentuk untuk mekanisme menekan adalah menggunakan kaedah carta morfologi. Prototaip mekanisme ini dipasang ke pencetak 3D FDM yang sedia ada untuk memberikan tekanan ke atas filamen ketika proses mencetak. Untuk menguji mekanisme menekan, sampel tulang anjing telah dicetak. Sampel asal dibandingkan dengan sampel yang dikenakan tekanan ke atasnya. Ketumpatan dan kelajuan mencetak merupakan parameter yang dipilih untuk diuji. Melalui ukuran dimensi, ujian kekasaran permukaan, ujian tegangan, dan ujian keliangan, sifat mekanik sampel yang dicetak oleh mekanisme diperoleh. Keputusan menunjukkan sampel yang menerima tekanan untuk ketumpatan penuh lebih baik berbanding sampel asal. Untuk parameter kelajuan mencetak, sampel yang menerima tekanan ada menambah baik peratusan keliangan sampel tetapi hanya untuk kelajuan mencetak yang perlahan. Mekanisme menekan memang membantu meningkatkan kualiti objek yang dicetak, tetapi dalam pada masa yang sama memberi kesan kepada ukuran asal sampel tersebut.

ACKNOWLEDGEMENT

I would like to pay special thankfulness and appreciation to my supervisor, Associate Professor Ir. Dr. Mohd Rizal Bin Alkahari for giving me this chance to work my final year project with him. Thanks for his vital support, assistance and encouragement made it possible for me to complete this project.

Secondly, I would like to express my gratitude to a senior named Nor Ana Binti Rosli for spending her time to guide me on this project. She does not hesitate to share her vast knowledge in the field of 3D printer and explain what experiment need to be carried out. In addition, I would like to thank all technicians from mechanic structure lab for their assistance and efforts in the lab and analysis works.

Special thanks to all my friends, beloved mother, father and siblings for support whether financially or morally. Lastly, thank you to everyone who had been parts of my journey to complete this degree.

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ABBREVIATION

3D	– 3 Dimensional
AM	– Additive Manufacturing
ABS	– Acrylonitrile Butadiene Styrene
CAD	– Computer-Aided Design
DC	– Direct Current
FDM	– Fused Deposition Modeling
PLA	– Polylactic Acid
RP	– Rapid Prototyping
SLA	– Stereo Lithography
SLS	– Selective Laser Sintering
STL	– Standard Tessellation Language
USB	– Universal Serial Bus
UV	– Ultraviolet

CHAPTER 1

INTRODUCTION

1.1 Background

Three-dimensional printing is a process where a digital model is turned into a physical three-dimensional object by adding material layer by layer until it complete at a time (O. Diegel, 2014). This is where the term of additive manufacturing come from. Nowadays, three-dimensional printing is not uncommon as it used to be. Three-dimensional printing is now being used whether in medic, industries and even for personal use. Heavy industries in production usually use three-dimensional printing as a test model before they start their mass production by using injection moulding. This is because based on from (Anonymous,2018) three-dimensional product that are printed can be analyse to review the design to detect any problem in the design. This can save the company a lot of money. Despite 3D printing process having progress rapidly, there are still several area that can still be improve. One is about the strength and the porosity of the printed object. The most interesting idea to tackle this problem is to apply pressure after printing each layer. By doing this, each layer of filament that are printed can be flatten and make it stronger.

1.2 Problem Statement

In 3D printed object, the mechanical properties of it is lack in strength. This lack of strength is because the filament that are arrange layer by layer is circular in shape. This as a result can produce many porous areas for the printed object. As the amount of porous increase, the strength of the printed object decrease.

1.3 Objectives

The objectives of this project are as follows:

- To design new pressing mechanism during 3D printing.
- To fabricate additional mechanism as attachment to the existing 3D printer.
- To analyse the effectiveness of the developed system.

1.4 Scope of Project

The scope of this project are as follows:

- Using low cost 3D printer (open source system / entry level printer)
- Using FDM process parameter such as layer thickness and infill density
- Using thermoplastic material such as ABS and PLA.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focus more on the project development that is base from the previous studies. Any study that were related to the project were referred to help better understanding about this project such as the quality of the object printed by FDM. 3D printer that are integrated with pressing mechanism to enhance the structure of the object printed were never find before because this project are the first of its kind. This pressing mechanism also help to improve the quality of the product. The mechanism of the 3D printer integrated with pressing mechanism were explained in this chapter. Additive manufacturing also were explained briefly in this chapter.

2.2 History

3D printing uses computer technology to create solid objects of three dimensions. 3D printing combines thin horizontal cross sections of the additive process or layering of the material with a computer program for printing solid objects. You can create almost anything from 3D printing, including toys, weapons or parts of the machine. The history of 3D printing is important in order to understand the future of production.

Japanese inventor Hideo Kodama in 1981 was the first person recorded attempting 3D printing in the additive process. He created a product using UV lights to harden polymers and create solid objects. Charles Hull invented stereolithography, a 3D printing process that uses technology to create prototype version before manufacture the actual product. This way, more money and time can be save because the company can test it on the prototype rather test it on the actual product. The object is layer by layer printed, solvent rinsed, and ultraviolet light hardened. Computer Aided Design (CAD) are used to create 3D models.

Figure 2.1: SLA-1 invented by Charles Hull in 1987 (H. Bensoussan, 2016).

Figure 2.1 shows the first-ever 3D printer that are invented by Charles Hull. This 3D printer transform manufacturing process and enabled designs with complexity.

Selective Laser Sintering (SLS) is another more advanced 3D printing/additive manufacturing form. It uses additive production and a polymer–usually nylon–powder to create objects. SLS uses a laser to combine the powder, layer by layer, in more complex forms than SLA can create. Fused Deposition Modeling (FDM) by Scott Crump is the most common form of 3D printing nowadays. It is known as the "3D desktop printers" because it is the most widely used technology form. The printer heats a thermoplastic cable into a liquid form in order to form an object and extrudes it layer by layer (Brooke Hahn, 2018).

2.3 Rapid Prototyping

Rapid Prototyping (RP) is a technology used to construct a physical model or prototype directly from three-dimensional Computer-Aided-Design (3D CAD) data in a very short time (Harun et al., 2016). The 3D printer enable designers to quickly create tangible prototypes rather than two-dimensional images of their designs. Such models have many uses. They provide excellent visual aids to communicate ideas within colleagues or customers in addition to design testing (Mahindru & Mahendru, 2013).

2.3.1 General Principles of 3D Printing

This is the general process of 3D printing:

1. Designing 3D model. Any type of CAD Software that can design 3D model can be use.
2. Generation of STL files. As there are many CAD software, hence to standardized and bring uniformity all files are saved in .STL format. Where STL is stand for Standard Tessellation Language.
3. Support are generate for overhang parts.
4. STL files are check for any defect.
5. STL file is transmit to slicing software.
6. The STL model is slice into thin cross sectional layer (Slic3r)
7. Part building layer by layer
8. Finishing prototype

Firstly, it begins with 3D product modelling. There are many type of software for 3D designing in the market nowadays. All of design software have their own pros and cons, so user have to decide which software suit best. After the designing process is finish, the design have to be convert to the CAD drawing to a STL file. Different surfaces of a CAD model are approximate in a piece by a series of triangles and the vertices of triangles and their surface norms are listed in tessellation. After the STL file are generate, overhang part in the drawing need to have support generate for it. Usually, slicing software can auto generate support for this overhang parts. Then, these STL files are check for any defects and are repaired if found to be defective. Free defect STL files are used to input different slicing software such as Slic3r (PandeyM. & Pulak, 2010).

Then, the layer's thickness need to be choose. Next step is the actual component construction. RP machines make a single layer of polymers, paper or powdered metal at a time. Most machines are quite self - contained and need little human intervention. Finally, it is all about post processing. This means that the prototype is removed from the machine and all supports are removed. Prior to use, some photosensitive materials must be completely cured. Prototypes may also require small surface treatment and cleaning. The model's appearance and durability are improved by sanding, sealing or painting (Mahindru & Mahendru, 2013).

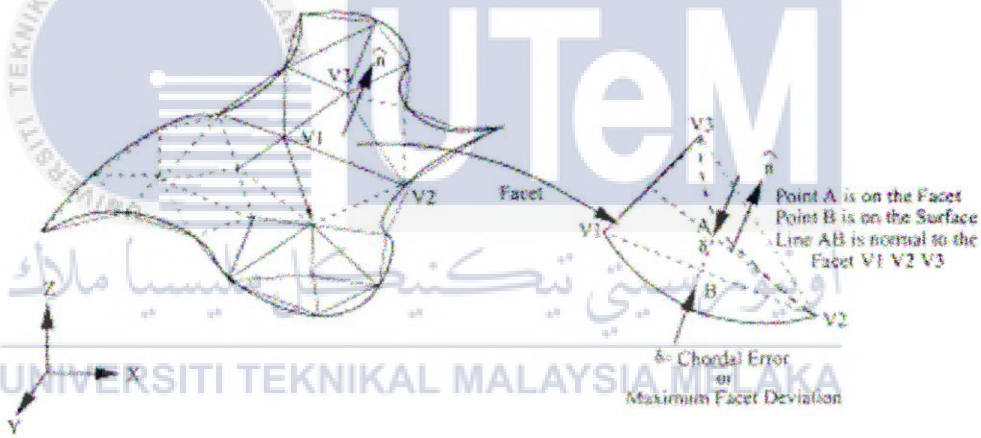


Figure 2.2: Tessellation of surface of CAD model (PandeyM. & Pulak, 2010)

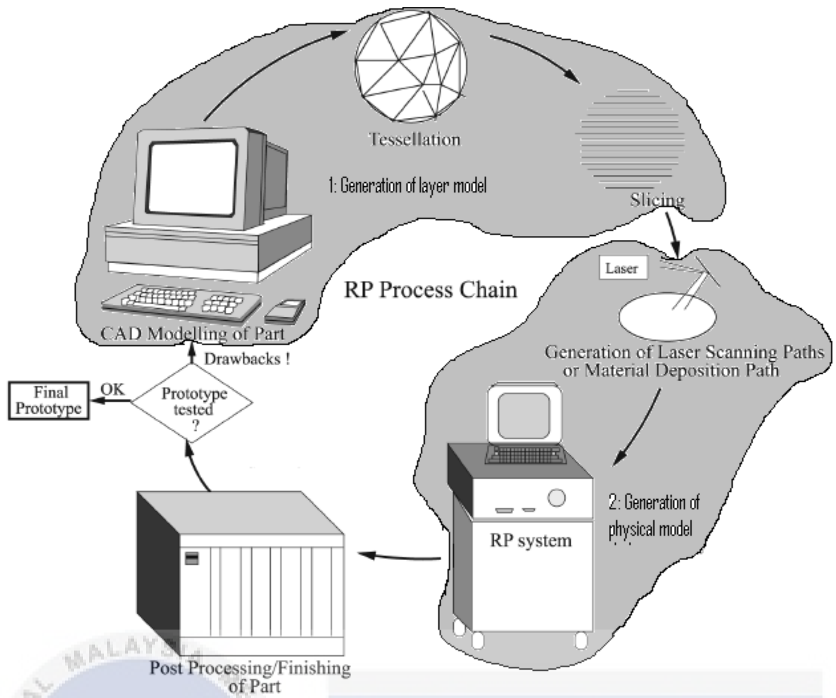


Figure 2.3 : Rapid Prototyping process chain (PandeyM. & Pulak, 2010)

Figure 2.3 shows the rapid prototyping process from drawing part in CAD software, then generate layer model, next slice the model, then generate laser scanning path, next generation of physical model and lastly post processing of finishing part. If the prototype past the test conducted then the cycle finish, if not repeat the cycle from the first process.

2.4 Technique in 3D Printing

There are at least six different 3D printing techniques available in the market, each with unique strengths. As 3D printing techniques are increasingly used in no prototyping applications, these techniques are often referred to as solid free - form manufacturing, computer-automated production or layered production. Layered production actually explains the process used by all commercial manufacturing techniques. There are many techniques in 3D printing but the technique that are focus in this project is FDM. The six RP techniques available are as follows:

Table 2.1: Technique of Rapid Prototyping from (Wikipedia, n.d.)

Types	**Techniques**	**Materials**
Extrusion	Fused deposition Modeling (FDM)	Plastic
Laminated	Laminated Object Manufacture (LOM)	Paper, Metal foil
Light Polymerize	Stereo Lithography (SLA)	Photopolymer
Powder Bed	Selective Laser Sintering (SLS)	Thermoplastic
	Solid Ground Curing (SGC)	Photosensitive polymer
	3D Ink Jet Printing	Metal Alloy

2.4.1 Fused Deposition Modeling (FDM)

A continuous filament of a thermoplastic polymer is use in the FDM method for printing 3D material layers. The filament is heated to a semi-liquid state at the nozzle and then extruded on the platform or on previously printed layers. The thermoplasticity of the polymer filament is an essential feature of this method, which allows the filaments to fuse together during printing and to solidify after printing at room temperature. The thickness of the layer, width and orientation of filaments and air gap (in the same layer or between layers) are the main processing parameters affecting the mechanical properties of printed parts. The main cause of mechanical weakness was the interlayer distortion. The main advantages of FDM are low costs, high speed and process simplicity. On the other hand, the main drawbacks of FDM are weak mechanical properties, layer by layer appearance, poor surface quality and a limited number of thermoplastic materials (Mahindru & Mahendru, 2013). Recent FDM systems include two nozzles, one for material part and one for material support. The material is relatively poor in quality and can be easily broken once the whole part is deposited and removed from the substrate (Pandey, 2000).

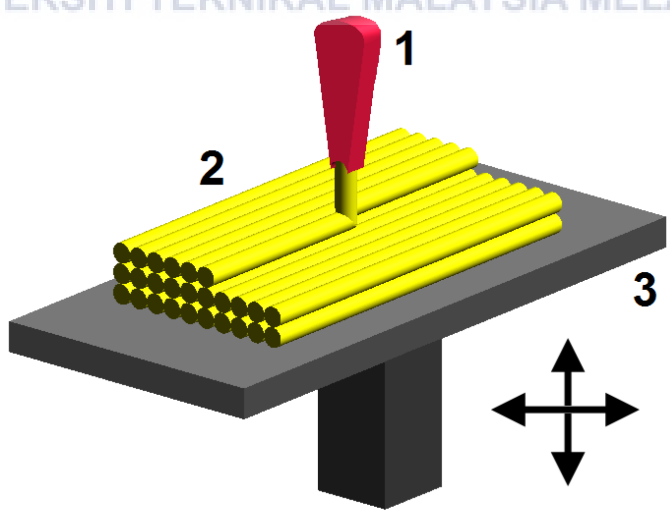


Figure 2.4: FDM (Lu, Guido, Aning, & Reynolds, 2017)

Figure 2.4 shows the FDM process. Number one show the nozzle ejecting molten material while number two present the deposited material. Number three is the axis of the controlled moveable table.

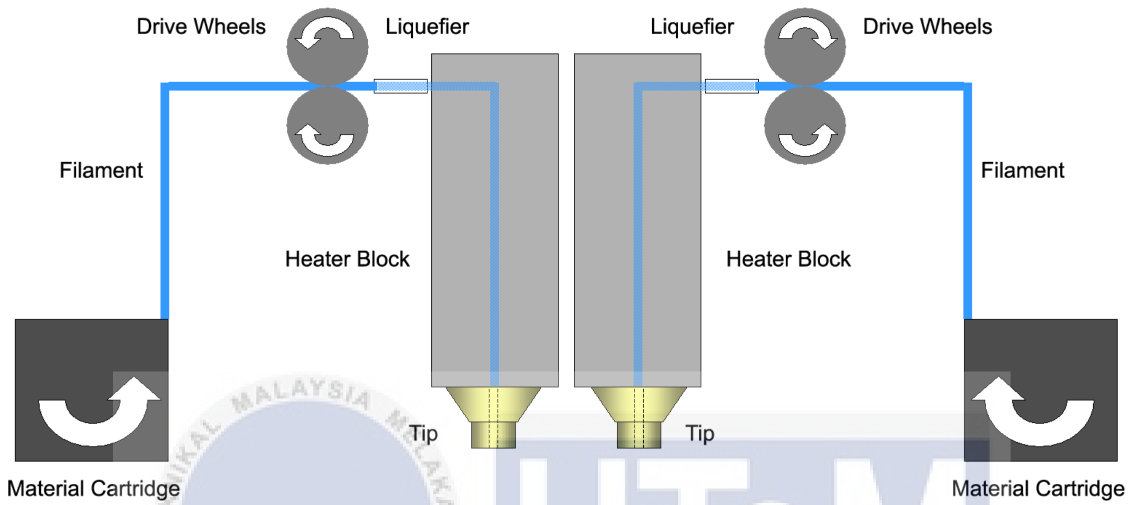


Figure 2.5: two nozzles, one for modeling material and one for support material

(Stelian Coros, n.d.)

2.5 Pressure

As we all know, human race keep improving the machine around us to help daily routine in life become easier. Same with additive manufacturing, even though everyone think it is already reach its limit, it actually can be better. A few past research study on improving additive manufacturing. Comparing the critical processing parameters of additive manufacturing with most conventional production processes, one factor in commercial additive manufacturing techniques is noticeably absent: the use of pressure (Jones, Wimpenny, & Gibbons, 2015). According to Jason B. Jones, David I. Wimpenny, Greg J Gibbons, 2015, pressure can improve the porosity and surface roughness of the printed object if the optimum level of pressure is applied. This is because according to Jason B. Jones, David I. Wimpenny, Greg J Gibbons, 2015, the softened layer will deformed and close porosity of the printed object.

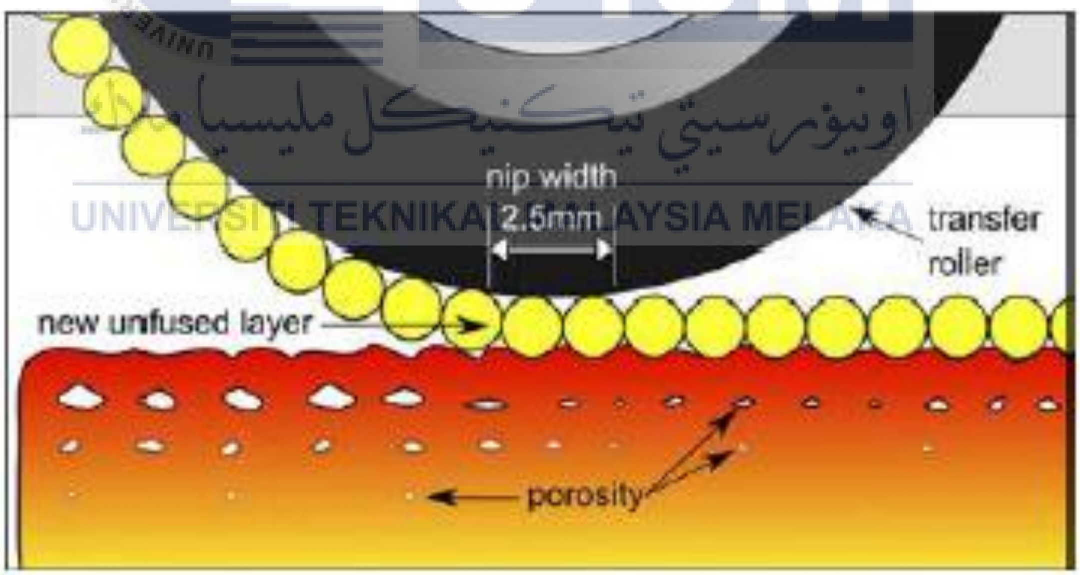


Figure 2.6: Pressure on uppermost layer surface (Jones et al., 2015)

2.5.1 Stainless Steel Plate

In this project, stainless steel plate was used as a medium that apply pressure to the uppermost layer of the soften material. This stainless steel plate is power by a small motor to vertical motion for it to apply pressure. The motor is power by USB cable that can be connect to any electronic device with a USB port.

2.6 Infill Density

Each layer of printed parts comprises of two primary components in terms of the printing method, which are perimeter and infill. The perimeter defines the outer part of the printed layer and may be thick or thin as the user wants. This not only offers the external appearance of the part, but it also serves the objective of keeping the part together. Even there are some parts printed hollow, there are parts that need structural support. In order to give the parts more structural resilience, infill is added to the inside of parameter. Infill is a percentage value that demonstrates how much material a solid model should be filled with when printed (Harpool, 2016). According to T.D. Harpool (2016), when selecting an infill pattern, there are several factors need to take into consideration, which are strength of the portion, time and material. In choosing an infill there are two main options, the pattern and the density of the infill.

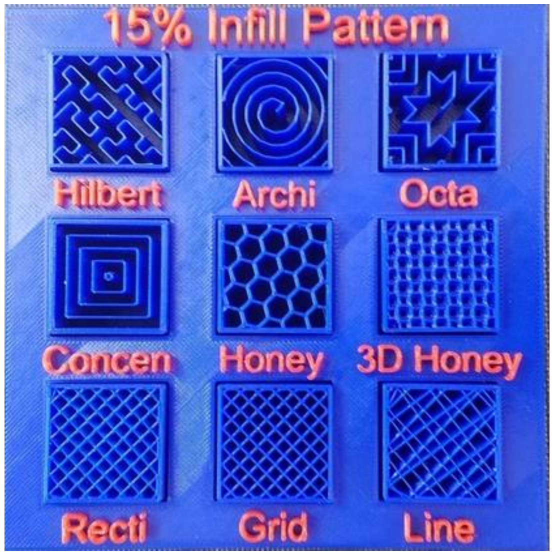


Figure 2.7: Infill patterns at 15% density of honeycomb, concentric, line, rectilinear, hilbert, archimedean chords, 3D honey, grid and octagram spiral (Blu Siber, n.d.).

The varieties of infill pattern can be seen in Figure 2.7. Each type of infill pattern have structural part that suit the pattern best.

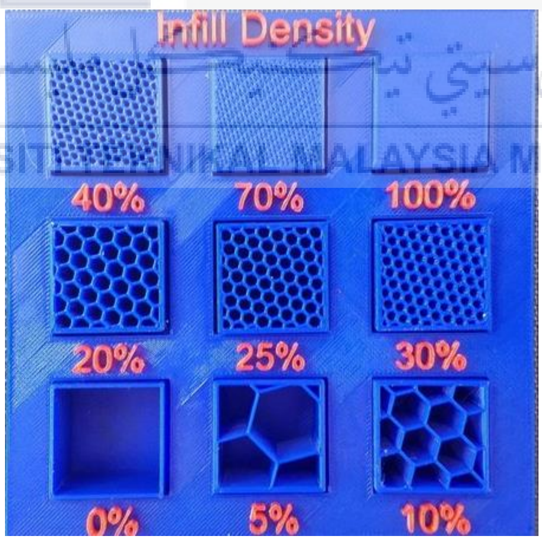


Figure 2.8: Different densities of honeycomb infill pattern (Blu Siber, n.d.).

As shown in Figure 2.8, it is the honeycomb infill pattern with different density. The higher infill density have more weight and strength compare to the lower infill density.

2.7 Printing Speed

Printing speed is define as the speed of 3D printer during printing object. Effects of printing can be divided into two categories, which is an influence on mechanical performance and influence on visual quality. For the influence of printing speed on mechanical performance, based on research from (Anonymous, 2015) there appears to be a slight increase in max stress with a higher print speed. One hypothesis suggested that when the item is printed more quickly, the specimen has less time to cool down, and the bond and strength between the layers of the 3D printed specimen is improved (Tyler Koslow, 2015). As for the effect of printing speed on visual quality, slower printing speed produce a better quality outcome. This is because of the filament deposited at high speed is less even compare to at low speed (Anonymous, 2015).

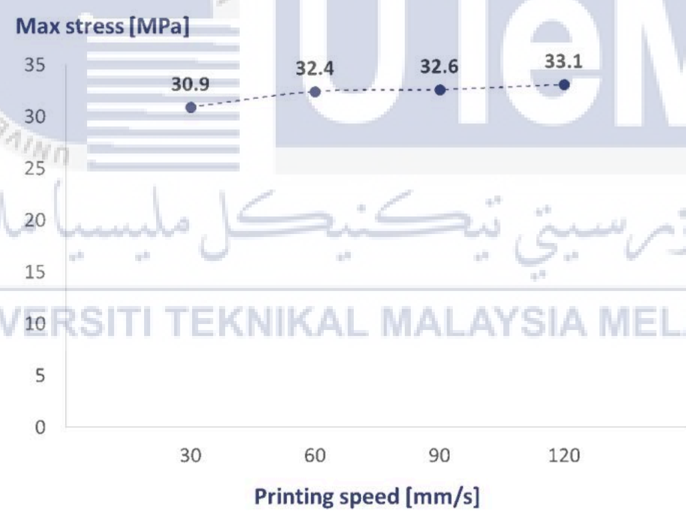


Figure 2.9: graph of max stress against printing speed (Anonymous, 2015).

Figure 2.9 shows the result of previous studies between max stress against the printing speed of a sample. From the figure, it can be conclude that high printing speed can increase the max stress of a printed specimen.

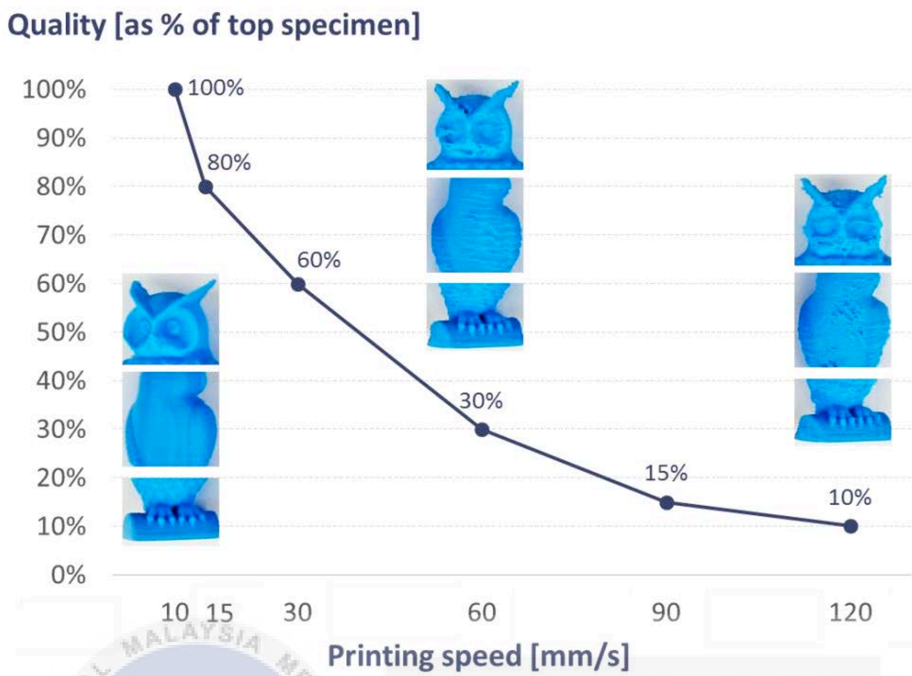


Figure 2.10: Quality of printed specimen against printing speed

The quality of printed specimen for different printing speed are shown in Figure 2.10. From the figure. It shows that at high printing speed, the quality of the printed material is decreasing. This is because the material deposited are not even and the machine may vibrate at high speed (Anonymous,2015).

2.8 Tensile Testing

Strength is generally any material's primary problem. Tensile testing is conducted to see the material's behaviour to some stage of stress or plastic deformation or to test the boundaries of the material by taking the ultimate failure. Figure 2.11 shows the general concept of the tensile test specimen. For its function, the shape of the specimen is widely known as a "dog bone." Each specimen is equipped with a grip section on each end at the start of the test, which provides sufficient space for the machine to apply the force. A narrower segment called gage section links each grip section (Park, 2004).

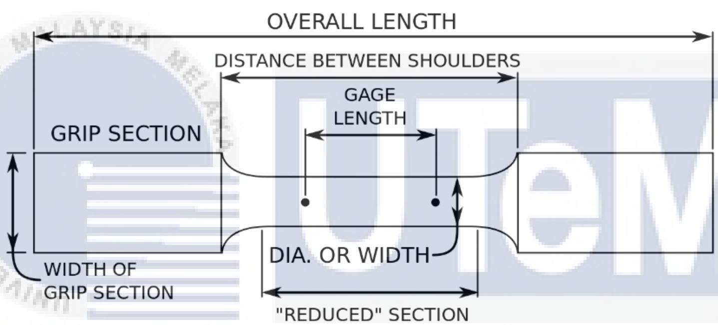


Figure 2.11: Test specimen nomenclature (Wikipedia, n.d.)

The gap between the gage and grip segments should be intended to be big enough to avoid grip ends within the gage segment from restricting deformation. The specimen is tested after material and shape of the specimen have been identified. An axial force applied to an initial length specimen elongates it, leading in the cross-sectional region being reduced until a fracture happens (J.R. Davis, 2004).

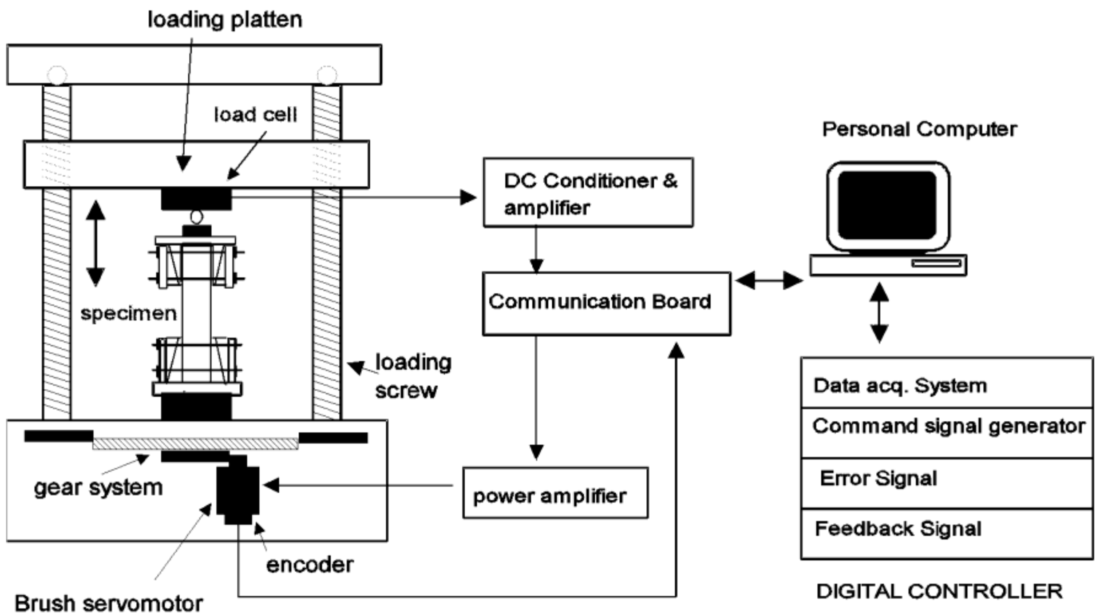


Figure 2.12: Schematic Diagram of Tensile Testing Machine (Abhishek Sagar, 2015)

2.8 Summary of Chapter 2

In conclusion, it is possible to gain understanding by examining the context of this research from the appropriate journal papers and books. The methodology for this project is explained in the next chapter gather all the information needed for this project.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explained about the project methodology. The process flow chart was produced and the method for carrying out the project is explain briefly. This chapter consist of process that need to be done in order to complete the project.

3.2 Project Flow Chart

A flowchart is a diagram sort that depicts a process or workflow. For the starting of this project, a literature review was prepared. All related articles, journals, or any materials that are relevant for this project were specified. The information that were obtained in the literature review were used for product design specification. In the product design specification stage, several specifications were listed to be chosen. After combining all specifications, two conceptual design were prepared. Then, a better concept design was chosen for detail design. After detail design was finished, came the fabrication stage. Fabrication stage involved the assembly of the pressing mechanism. After the pressing mechanism finish assembled, a test were conducted using samples that are printed with pressing mechanism and original samples. Then, the result were tabulated and analysed. Finally, a report on this project was written.

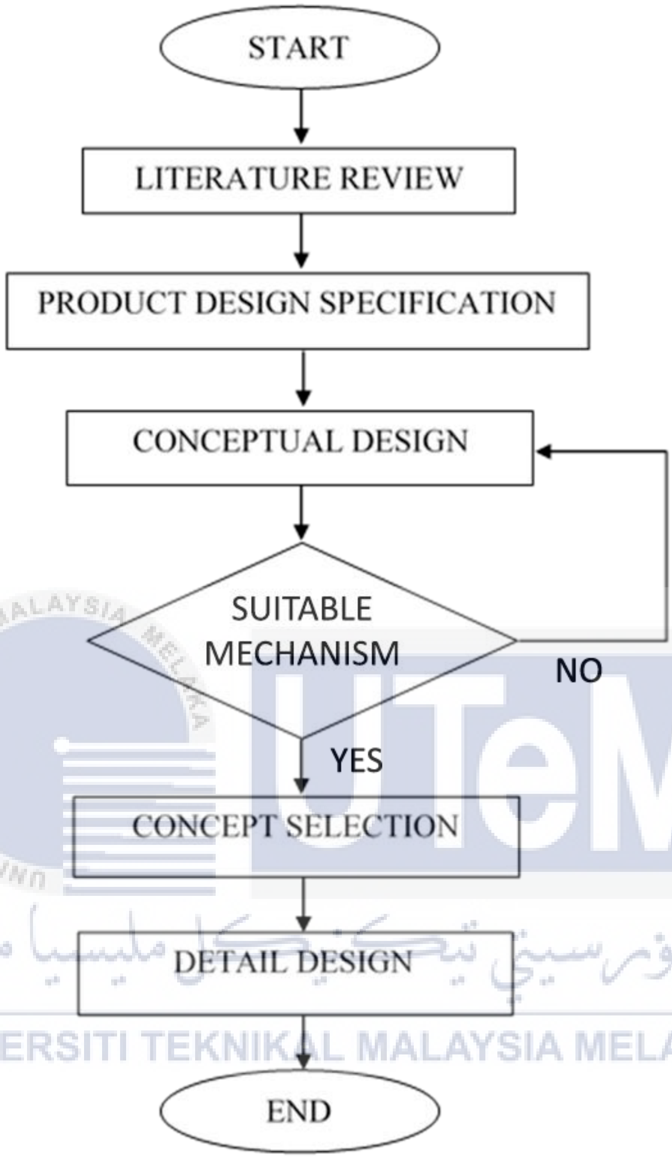
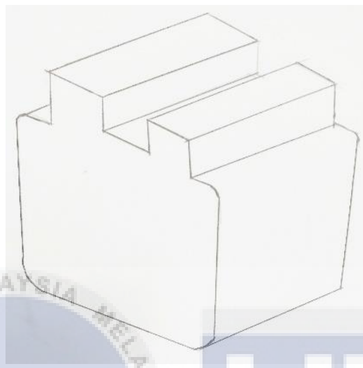
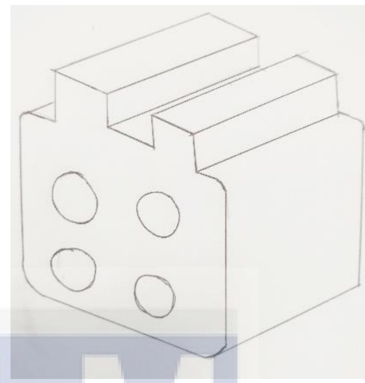
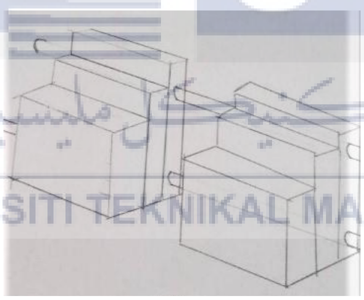
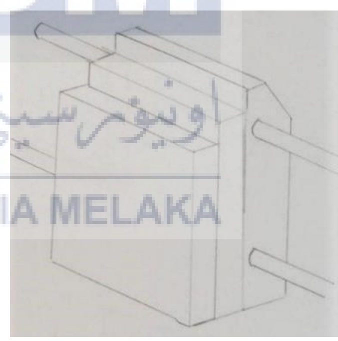
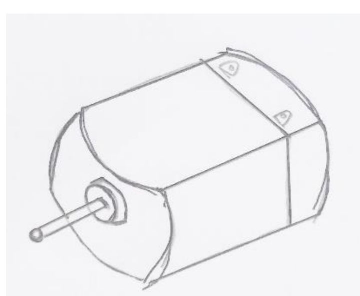
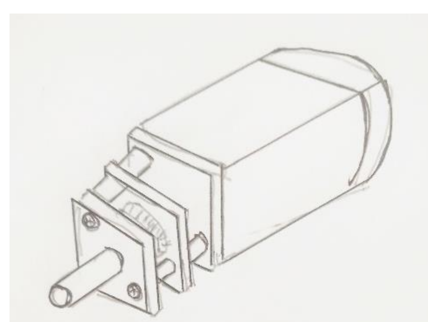
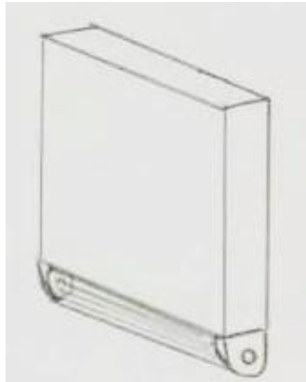
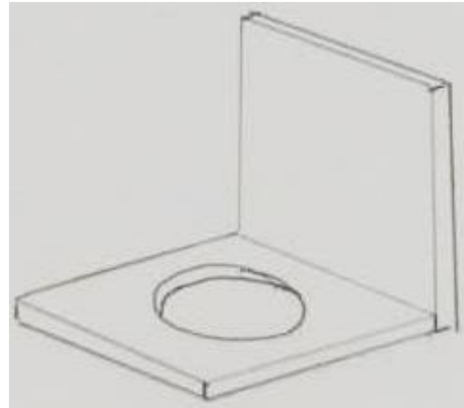


Figure 3.1: Flow Chart of The Project

3.3 Morphological Chart

Table 3.1: Morphological chart for the project

Characteristic		
Type of motor housing	 Normal motor housing	 Motor housing with air ways for stepper motor
Number of extruder used	 Dual extruder	 Single extruder
Type of motor used	 Tamiya motor	 Miniature DC high torque motor

Additional part	 Roller	 Plate
Type of material for additional part	 Aluminium	 Steel
Movement for additional part	 Vertical movement	 Horizontal movement

3.4 Concept Design

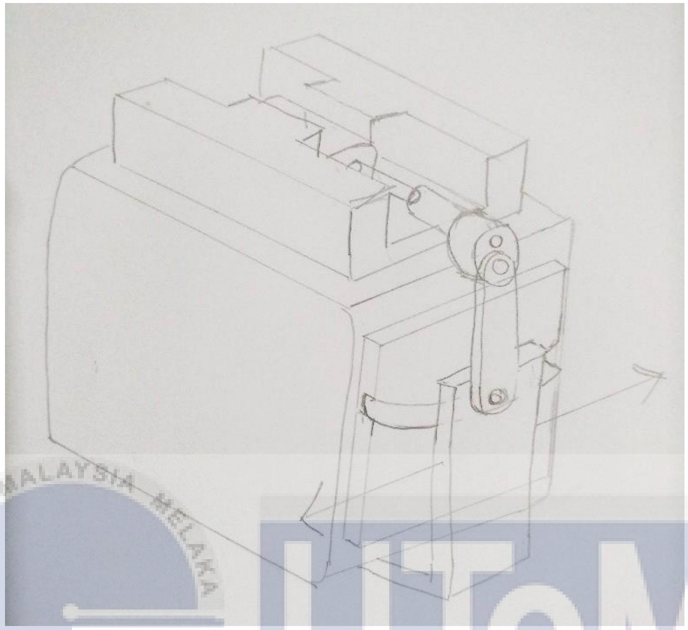


Figure 3.2: Concept design 1

Figure 3.2 shows a concept design that combine several characteristics from the morphological chart such as normal motor housing, tamiya motor, aluminium plate, single extruder and horizontal movement. The advantage of this design is that it use a higher motor power so the force that it transmit are larger. The disadvantages of this design are that it use horizontal movement for the aluminium plate and the motor housing traps heat of the stepper motor than can reduce lifespan of the stepper motor.

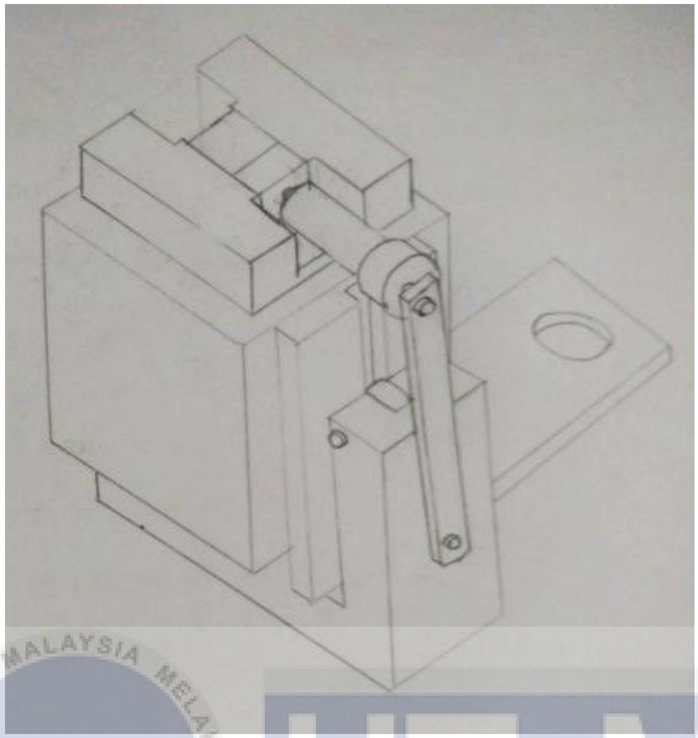


Figure 3.3: Concept design 2

Figure 3.3 shows a concept design that combine several characteristics from the morphological chart such as motor housing with air ways for stepper motor, miniature DC high torque motor, aluminium plate, single extruder and vertical movement. The advantages of this design is that it use a motor housing that have air ways for the stepper motor so the heat can flow and this concept also use vertical movement to apply pressure for the pressing mechanism so that the pressure apply evenly.

3.5 Prototype

Concept design 2 was chosen as final design. Then, the design was fabricate as prototype.

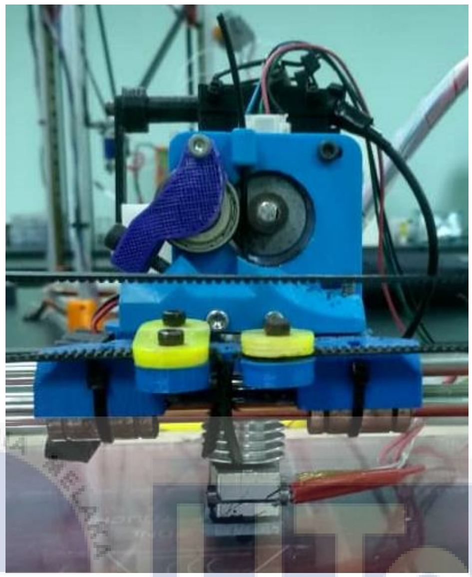


Figure 3.4: Front view of the extruder, nozzle and metal plate

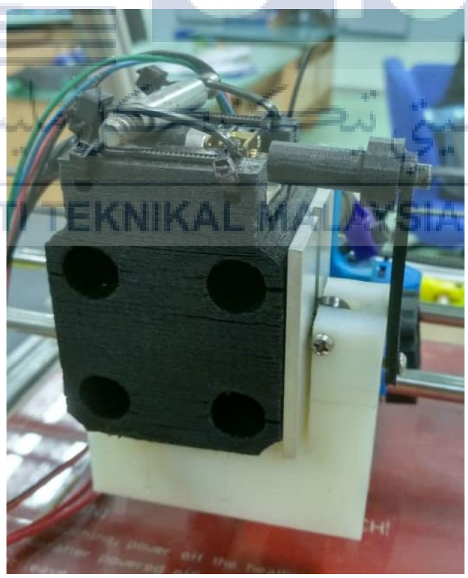


Figure 3.5: Back view of the motor part and metal plate

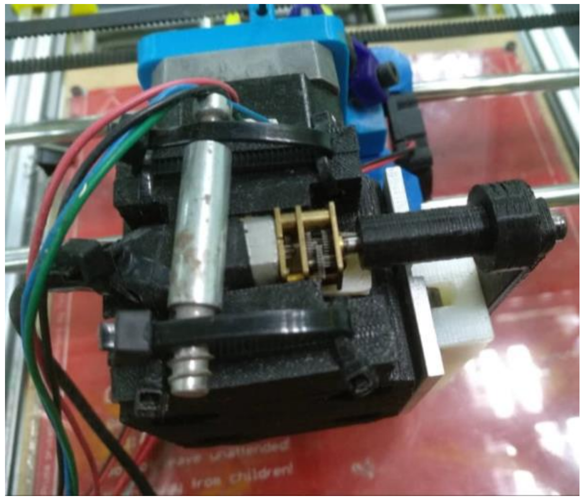


Figure 3.6: Top view of electric motor, extruder and nozzle

3.6 Analysis

The printed parts was analyse to get the performance of its mechanical properties.

3.6.1 Surface Roughness

TR200 Portable Surface Roughness Tester was used to measure the surface roughness of the printed parts. The method to use this equipment is simple. First, the samples must be levelled with the position indicator of the portable surface roughness tester. Then, just press the button that have play symbol on it. The results that were shown were recorded for result analysis.

Figure 3.7: TR200 Portable Surface Roughness Tester

3.6.2 Tensile Test

Tensile Test was conducted to analyse the strength of the printed samples. Figure 3.8 shows the Instron 8872 Universal Testing Machine that were used to conduct tensile test. As shown in the figure, the sample were grip at both end and were pulled apart until it break. Universal Testing Machine (UTM) Instron 8872 is a hydraulic double-acting servo actuator with a force capability of up to ±25 kN and is managed by Bluehill software.

Figure 3.8: Universal Testing Machine (UTM) Instron 8872

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Design Selection

After the selection of conceptual design for the additional mechanism for 3D printer, this chapter unfold more detail design of the pressing mechanism to look at the mechanism clearly. For the pressing mechanism, a miniature DC gear reducer low speed motor is place on top of the housing of the pressing mechanism. The reason for this decision is that the low speed motor helps the pressing mechanism to apply an optimum level of force to the layer of filament that were printed. Then, a connector is connect between the motor and a bar. The connector have inner bore at the end of bar that are not at the center of the circle, it is deliberately design like that so when the motor rotate, the bar then move vertically and in the same time move the steel plate.

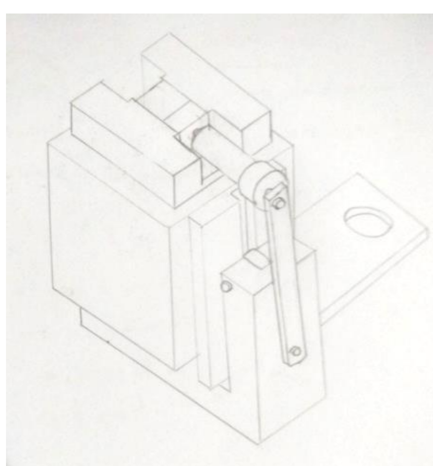


Figure 4.1: Sketch of the isometric view of pressing mechanism

4.2 Design Improvement

Preliminary design is not the best design to be manufactured without its features being improved. Improvisation must be done on the basis of the original idea of preliminary design. The motor's properties are the essential part of this pressing mechanism. When pressing the plastic filament, the selected motor should give optimum torque to the steel plate part. In the calculation, each parameter is important. Although it's just theoretical calculation, in the real situation it shouldn't have a big difference. The steel plate is changed to a larger wide steel plate to cover more area for improvisation.

4.3 Detail Design and Final Design

After some improvisations on its features, the final design is completed based on the preliminary design. In order to create the final design, every required aspect is considered. Although the manufacturing process is only responsible for creating the prototype, the design is important in determining this device's quality and reliability. All the orthographic drawing of the part which consist dimension are available at Appendix.

4.3.1 Pressing Mechanism Assemble Drawing

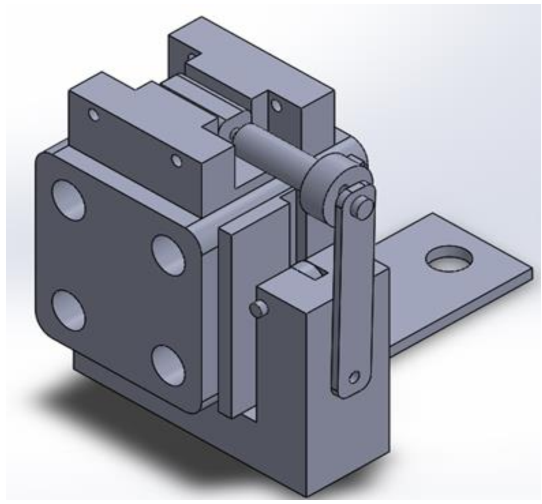


Figure 4.2: Assembly view of pressing mechanism

Figure 4.2 is the isometric view of the assemble of pressing mechanism. This are the complete look for the pressing mechanism after combining all parts together.

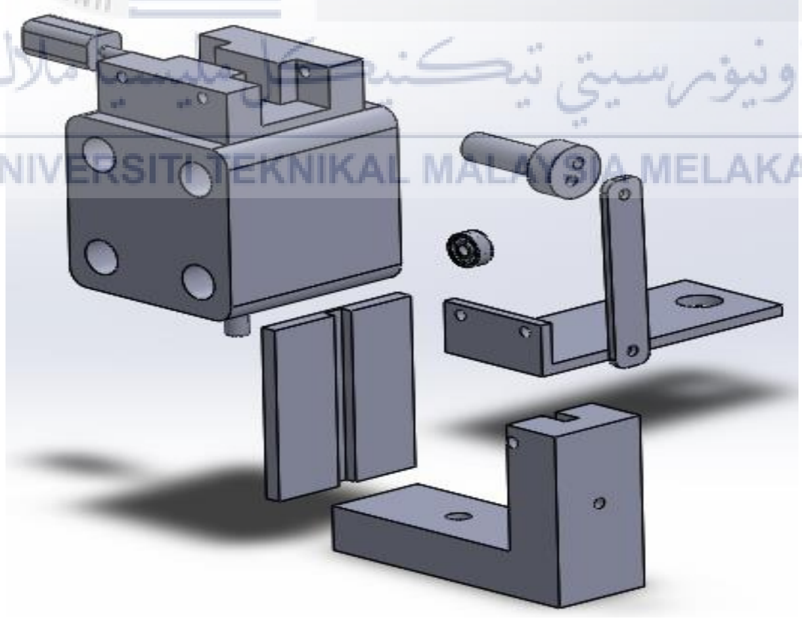


Figure 4.3: Exploded view of pressing mechanism

4.3.2 Parts for Pressing Mechanism

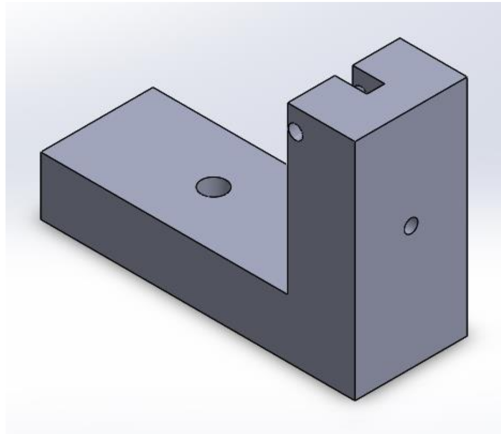


Figure 4.4: Bottom part of the pressing mechanism

Figure 4.4 shows the part that are place at the below of the motor housing. The plate also attach to this part.

Figure 4.5: Plastic bar that transfer the vertical movement

Figure 4.5 shows a bar that connect the movement from the motor to the bottom part of the pressing mechanism. This part is vital because it transfer the vertical movement of the pressing mechanism.

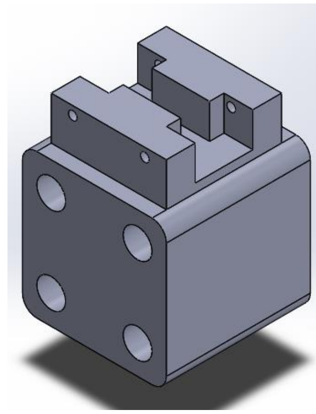


Figure 4.6: Housing of motor

Figure 4.6 shows the motor housing part of the pressing mechanism. The reason this motor housing part have holes on it is because to allow the movement of heat of stepper motor that are attach to the motor housing.

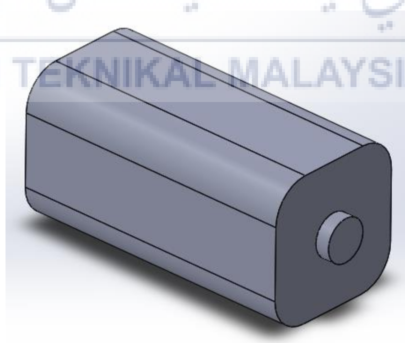


Figure 4.7: Motor

Figure 4.7 shows the drawing of motor according to its actual size. This motor is the part which trigger the vertical movement.

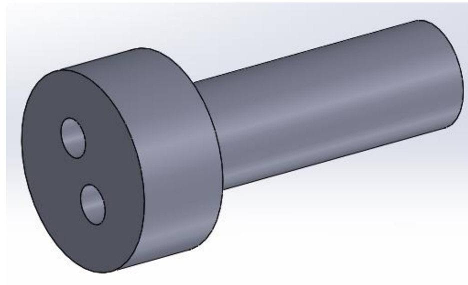


Figure 4.8: Connector that transfer motor rotation to the plastic bar

Figure 4.8 shows the part that connect motor and the plastic bar. This part used cam gear concept by creating hole slightly far from center of the circle to create vertical movement.

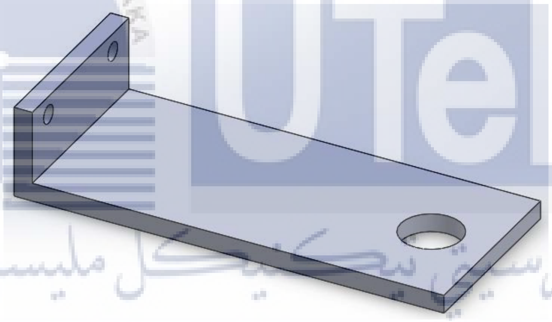


Figure 4.9: Steel plate

Figure 4.9 shows the steel plate part that apply the pressure for the pressing mechanism. The reason this part have the hole is to let the extruder pass through to print the filament.

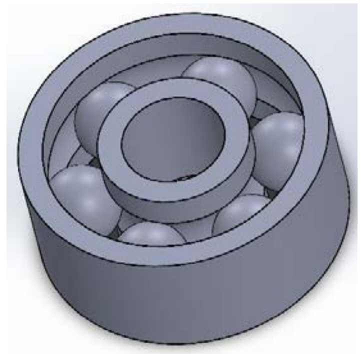


Figure 4.10: Bearing to help with the vertical movement

Figure 4.10 is the drawing of bearing. This part helps to guide the vertical movement of the pressing mechanism. This part is attach to the bottom part of pressing mechanism, it act as a wheel to smooth the vertical movement.

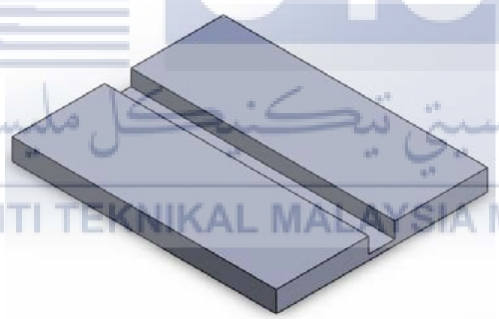


Figure 4.11: Steel path that attach to motor housing and help with bearing movement

Figure 4.11 shows the path that are attach to the motor housing. This path act as a railway to the bearing. This part ensure the movement of bottom part of pressing mechanism keep constant.

4.4 Force calculation

Motor that were selected during concept design was used to obtain the theoretical value for pressure applied to the specimen.

Miniature DC high torque motor specifications:

1. Voltage: 12V
2. No load speed: 104.72 rad/s
3. Load speed: 83.78 rad/s
4. Torque: 0.03 N/m

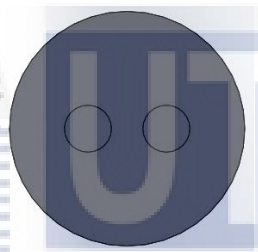


Figure 4.12: Distance between to circle: 0.005m

CALCULATION OF FORCE:

$$Force = Torque\ of\ motor\left(\frac{Newton}{Meter}\right) \times Length$$

= 0.03(0.0025)

= 0.000075 N

F = 7.5 x 10^-5 N

So, the amount of force that are applied to the plastic filament is 7.5 x 10^-5 N.

The calculation that are shown above are the method to calculate the force applied to the dog bone during printing process. The length value that is 0.0025m was obtain from the distance of the center of the circle to the center of one of the pair of the circle. The reason the length use that value is because that distance is the rotating distance the mechanism used.

4.5 Results

4.5.1 Experiment

Dog bone samples are used for testing in the experiments. The purpose of this experiment is to test the difference between original dog bone samples and with applied pressure dog bone samples. The tests that are conducted is surface roughness test, tensile strength test and porosity test. The length, wide and thickness are also measured to notify if there is any difference between samples. ASTM D638 is the standard for this dog bone design. The dimension of the dog bone sample is; length of 165 mm, wide of 19 mm and thickness of 4 mm. The samples are printed using 3D printer that have pressing mechanism integrate into it.

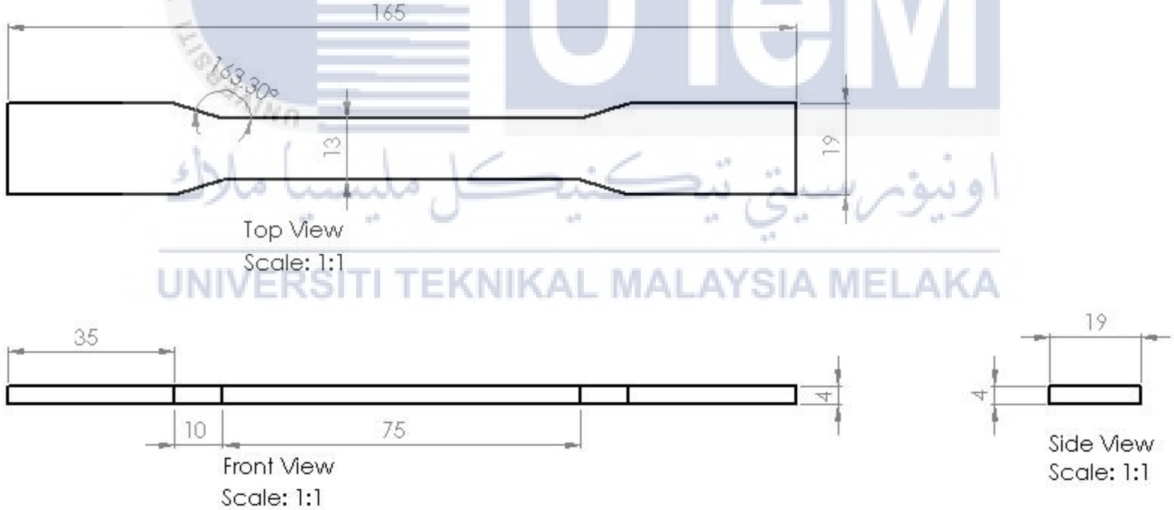


Figure 4.13: Dimension for dog bone drawing

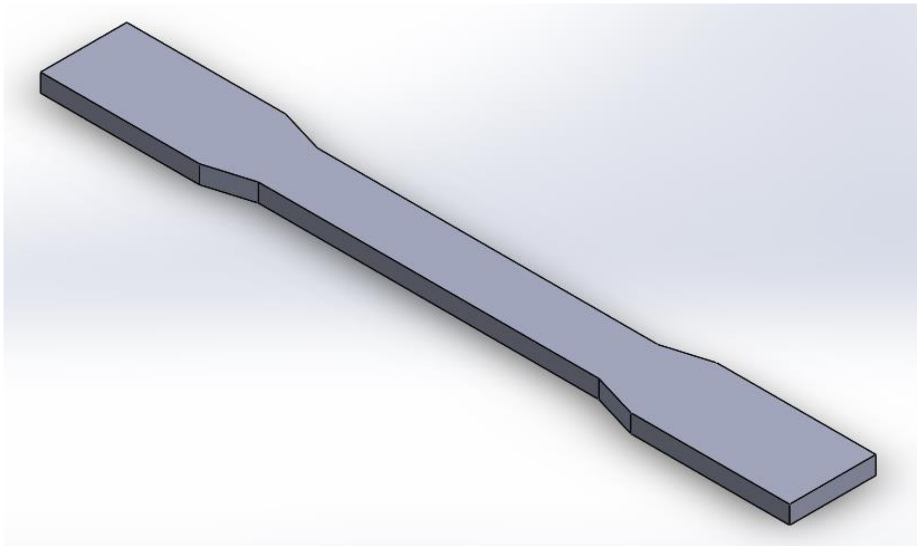


Figure 4.14: CAD drawing for dog bone sample in Solidworks

For this experiment, the dog bone sample parameters that was changed are the infill density and speed. The infill density for the original dog bone sample without pressure are 20%, 60%, and 100% while the speed used are 20 mm/s, 60 mm/s, and 100 mm/s. For the example of the dog bone with pressure, the density and speed experimented are 20%, 60%, and 100% for the density of the infill while 20 mm/s, 60 mm/s, and 100 mm/s for the speed.

Figure 4.15: Printed dog bone sample

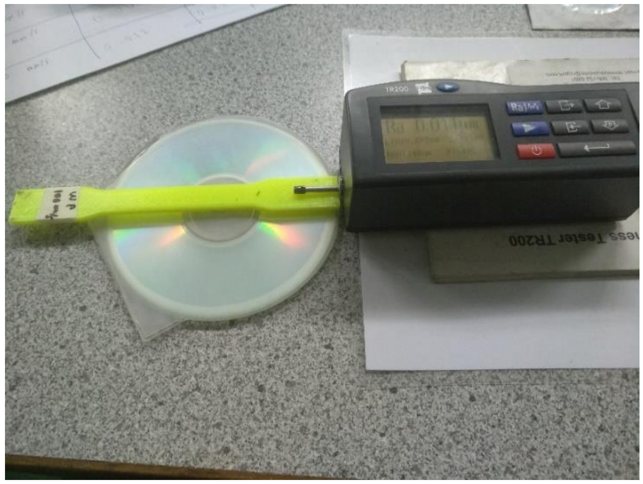


Figure 4.16: Sample of dog bone during surface roughness test

Figure 4.16 shows that the setup to test the surface roughness. The dog bone sample and the tip of portable surface roughness must be levelled so that it the readings recorded are precise and correct.

Figure 4.17: Dog bone sample after tensile test

Figure 4.17 shows the dog bone sample after the tensile test. The sample break in the middle as the result of the tensile test.

4.6 Effects of Fill Density

4.6.1 Length

Table 4.1: Length of Original Sample and Sample with Pressure for Fill Density Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Fill Density (%)	**Length (mm)**	**Fill Density (%)**	**Length (mm)**
20	164.6	20	165.0
60	164.6	60	165.0
100	164.6	100	165.0

Table 4.1 shows the data of the dog bone sample length. The length between the actual length and the sample length is slightly different. The length of sample were measured by using a Vernier caliper.

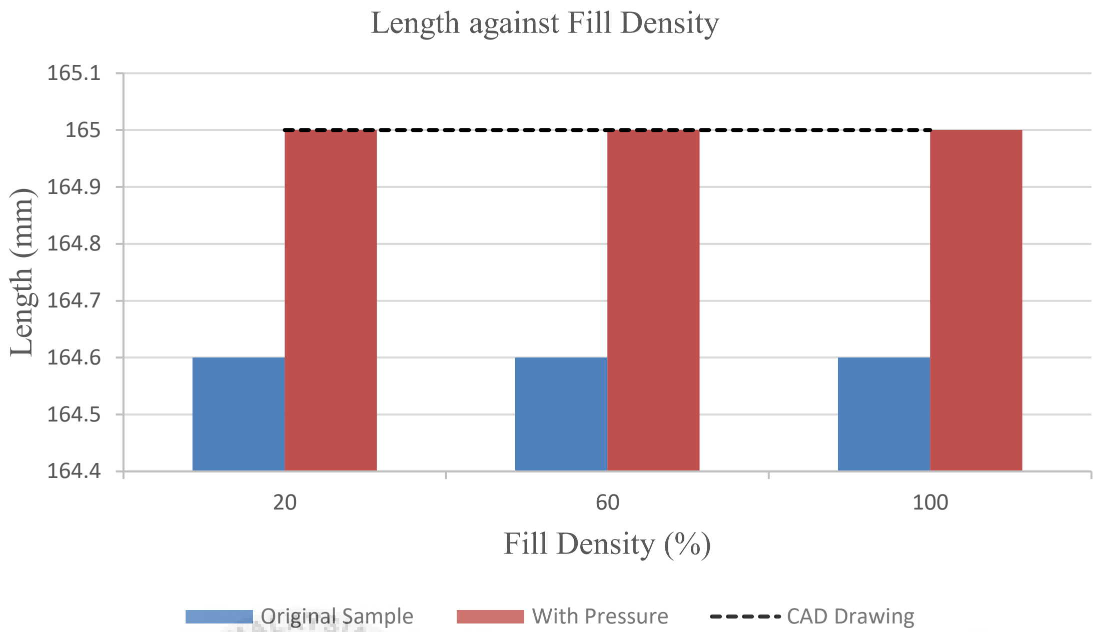


Figure 4.18: Length against fill density graph of original sample and sample with pressure

Figure 4.18 shows the length of the sample plotted against fill density. The length of all original sample should be the same as the CAD drawing because it was drew based on an actual dimension, which is 165.0 mm because there is no pressure applied to the filament during the printing process. As for the sample with pressure, all the length are constant at 165.0 mm. This is the effect from the pressure that were applied to the filament during the printing process and it cause the length of the sample to change.

4.6.2 Thickness

Table 4.2: Thickness of Original Sample and Sample with Pressure for Fill Density Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Fill Density (%)	**Thickness (mm)**	**Fill Density (%)**	**Thickness (mm)**
20	3.8	20	3.7
60	3.8	60	3.7
100	3.8	100	3.8

Table 4.2 shows the data of the dog bone sample thickness. The thickness between the actual thickness and the sample thickness is a bit different. The thickness of sample were measured by using a Vernier caliper.

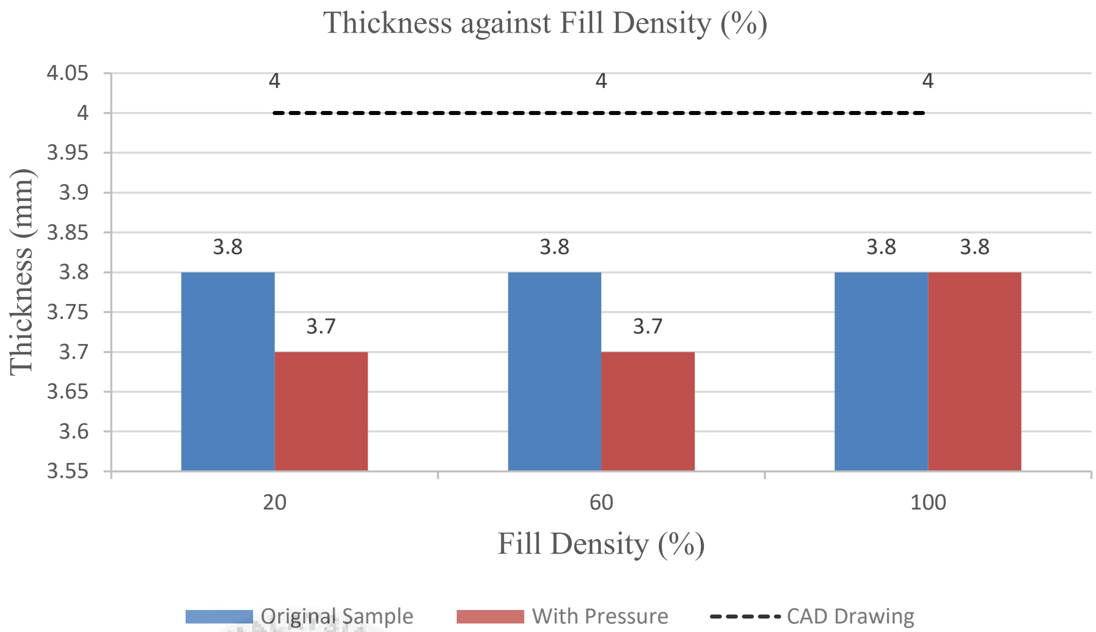


Figure 4.19: Thickness against fill density graph of original sample and sample with pressure

Figure 4.19 shows the thickness of the sample plotted against fill density. The thickness of original sample are constant at 3.8 mm. The length of all original sample should be the same as the CAD drawing because it was drew based on an actual dimension that is 4.0 mm because there is no pressure applied to the filament during the printing process. As for the sample with pressure, all the thickness are lower than the one from original sample because of the pressure that are applied to the filament. This is the effect from the pressure that were applied to the filament during the printing process and it cause the thickness of the sample to change.

4.6.3 Width

Table 4.3: Width of Original Sample and Sample with Pressure for Fill Density Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Fill Density (%)	**Width (mm)**	**Fill Density (%)**	**Width (mm)**
20	18.9	20	19.0
60	18.8	60	19.3
100	19.0	100	19.2

Table 4.3 shows the width of original dog bone sample and dog bone sample with pressure that were measured by using a Vernier caliper. The width of dog bone sample with pressure shows some increasing in number from actual dimension compared to original dog bone sample.

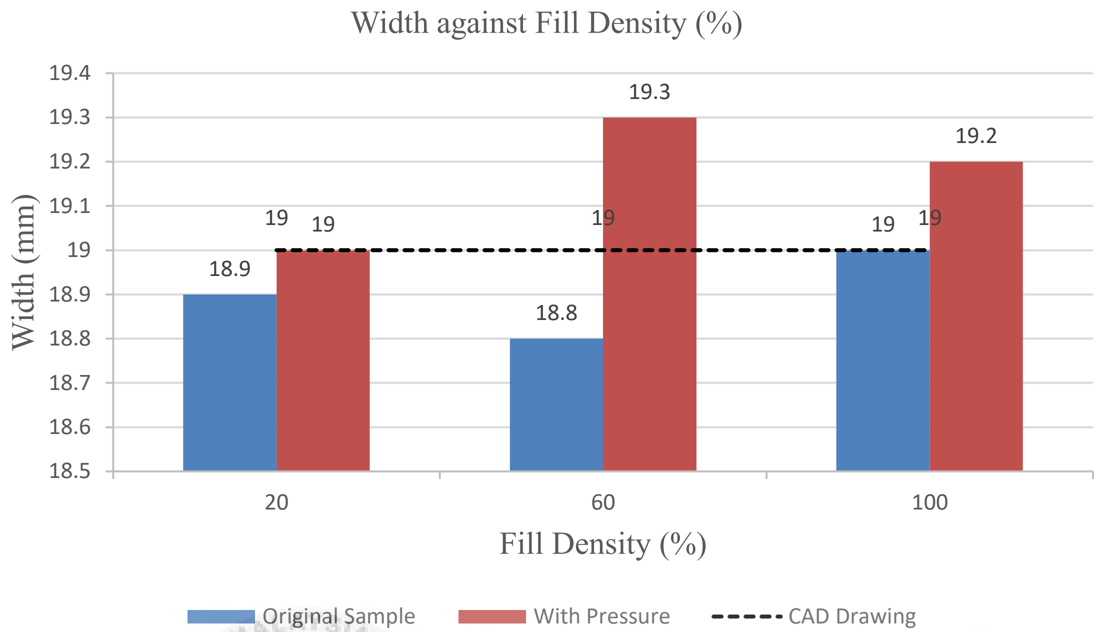


Figure 4.20: Width against fill density graph of original sample and sample with pressure

Figure 4.20 shows the width of the sample plotted against fill density. The width of original sample are range between 19.0 mm and 18.9 mm. The width of all original sample should be the same as the CAD drawing because it was drew based on an actual dimension that is 19.0 mm because there is no pressure applied to the filament during the printing process. As for the sample with pressure, the width are larger compared to original sample because of the pressure that were applied to the filament. This is the effect from the pressure that were applied to the filament during the printing process and it cause the width of the sample to change.

4.6.4 Surface Roughness

Table 4.4: Surface Roughness of Original Sample and Sample with Pressure for Fill Density Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Fill Density (%)	**Surface Roughness (µm)**	**Fill Density (%)**	**Surface Roughness (µm)**
20	2.9293	20	2.1192
60	2.1892	60	1.1583
100	0.0517	100	0.0037

Table 4.4 shows the surface roughness of all the samples, original and with pressure. The reading of the surface roughness is taken three times and the average reading is recorded in the table above. The readings of the surface roughness is decreasing while the value of fill density increasing.

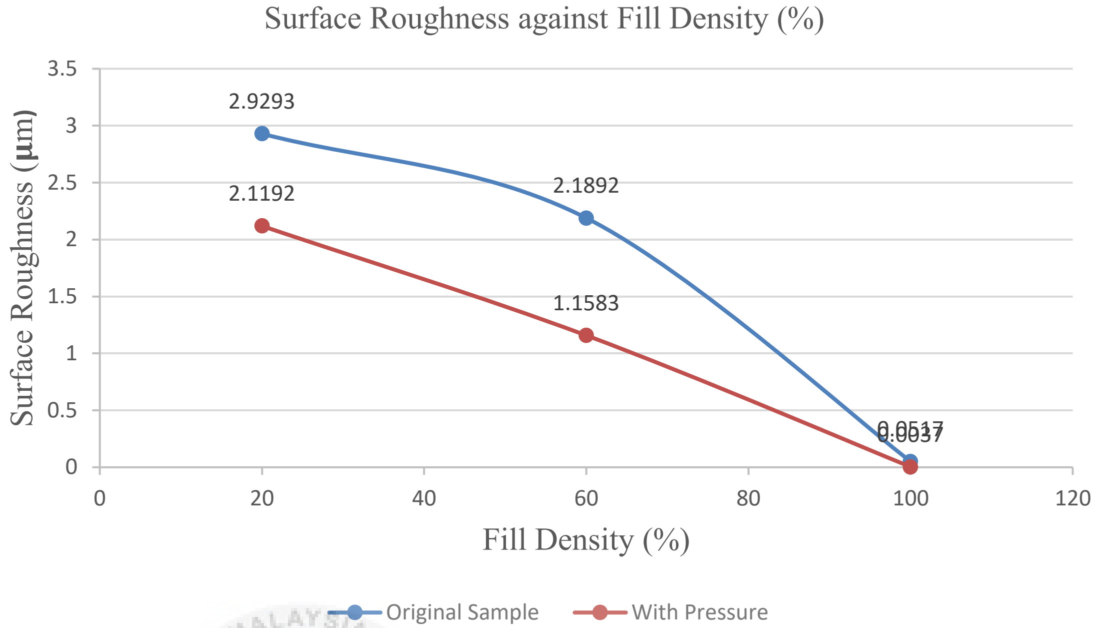


Figure 4.21: Surface roughness against fill density graph of original sample and sample with pressure

Figure 4.21 shows the graph of surface roughness against fill density. The graph a shows a declining pattern in surface roughness readings as the value of fill density increasing. Figure above also shows that the sample with pressure have smaller reading of surface roughness compare to original sample.

4.6.5 Tensile Test

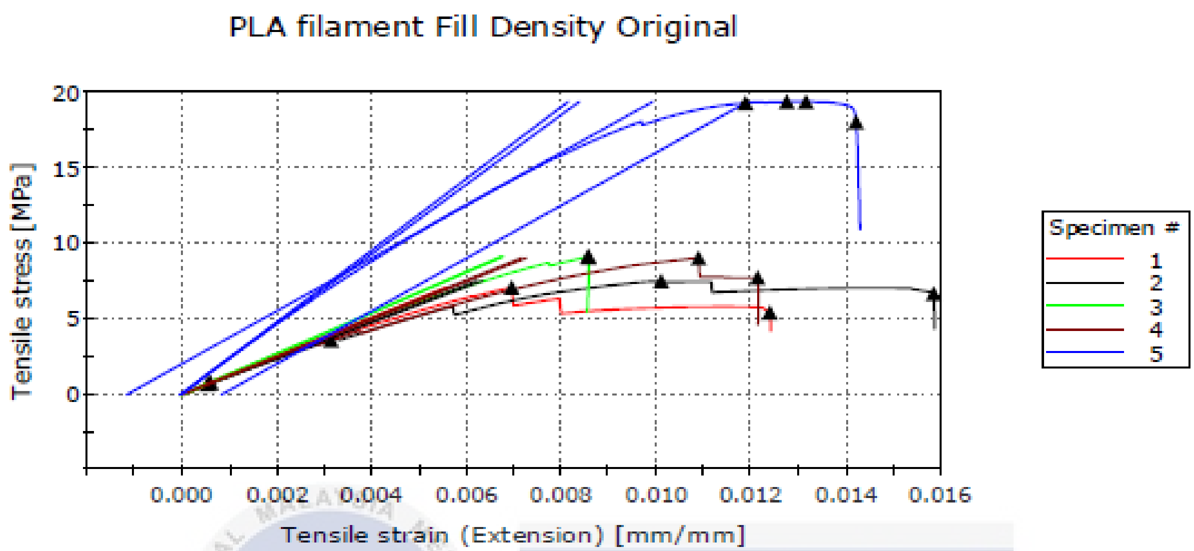


Figure 4.22: Tensile test graph of the original sample for fill density from Universal Testing Machine (UTM) Instron 8872

Figure 4.22 shows the graph of tensile stress against tensile strain, of the original dog bone sample. Specimen 1, 3, and 5 is original sample with fill density 20%, 60%, and 100% respectively. The maximum load that can be withstand by the sample is increase as the fill density of the sample increase.

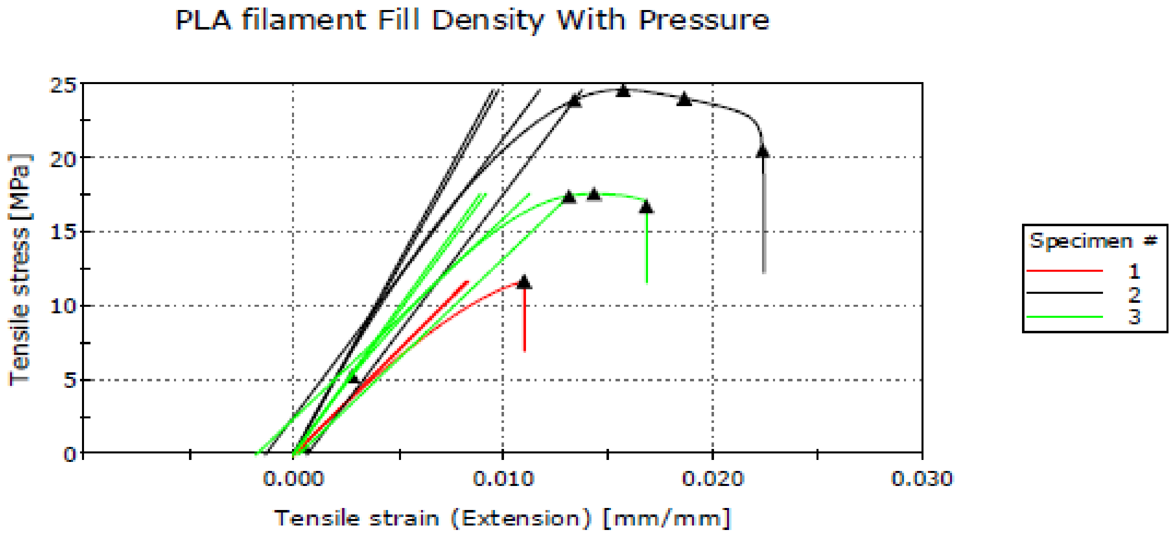


Figure 4.23: Tensile test graph of the sample with pressure from Universal Testing Machine (UTM) Instron 8872

Figure 4.23 shows the graph of tensile stress against tensile strain, of the dog bone sample with pressure. Specimen 1, 2, and 3 is sample with pressure with fill density of 20%, 100% and 60% respectively. The maximum load that can be withstand by the sample is increase as the fill density of the sample increase.

Table 4.5: Tensile Test of Original Sample for Fill Density

Original Sample (Fill Density)	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]	Load at Break (Standard) [N]
20	539.396	7.097	0.007	1257.353	413.864
60	693.610	9.126	0.009	1345.234	693.610
100	1471.316	19.359	0.013	2300.171	1369.239

Table 4.6: Tensile Test of Sample with Pressure for Fill Density

Original Sample (Fill Density)	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]	Load at Break (Standard) [N]
20	888.575	11.692	0.011	1398.509	888.575
100	1868.724	24.588	0.016	2503.675	1559.599
60	1337.065	17.593	0.014	1908.275	1273.689

Table 4.5 shows the tensile test data for original sample while Table 4.6 shows the tensile test for sample with pressure. The graph analysis was consist of maximum load, tensile stress, and tensile strain.

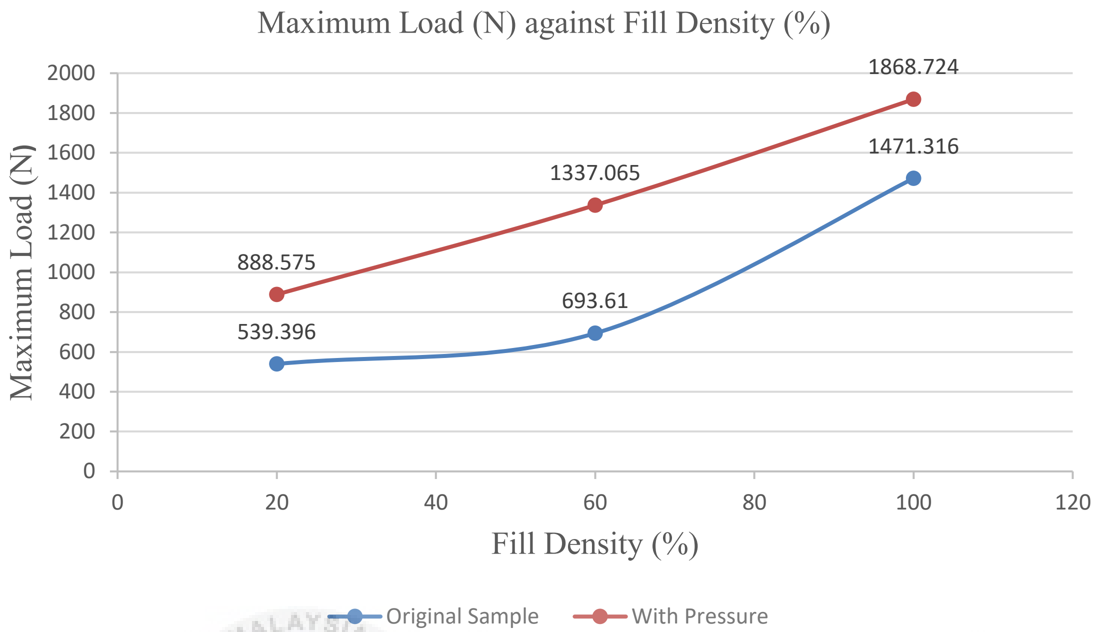


Figure 4.24: Maximum load against fill density of original sample and sample with pressure

Figure 4.24 shows the maximum load in Newton that were withstand by both original sample and sample with pressure. From the pattern of the graph, it shows that the maximum load is increase as the fill density increase. The entire sample with pressure also noted to have withstand higher maximum load compare to original sample from their respective class.

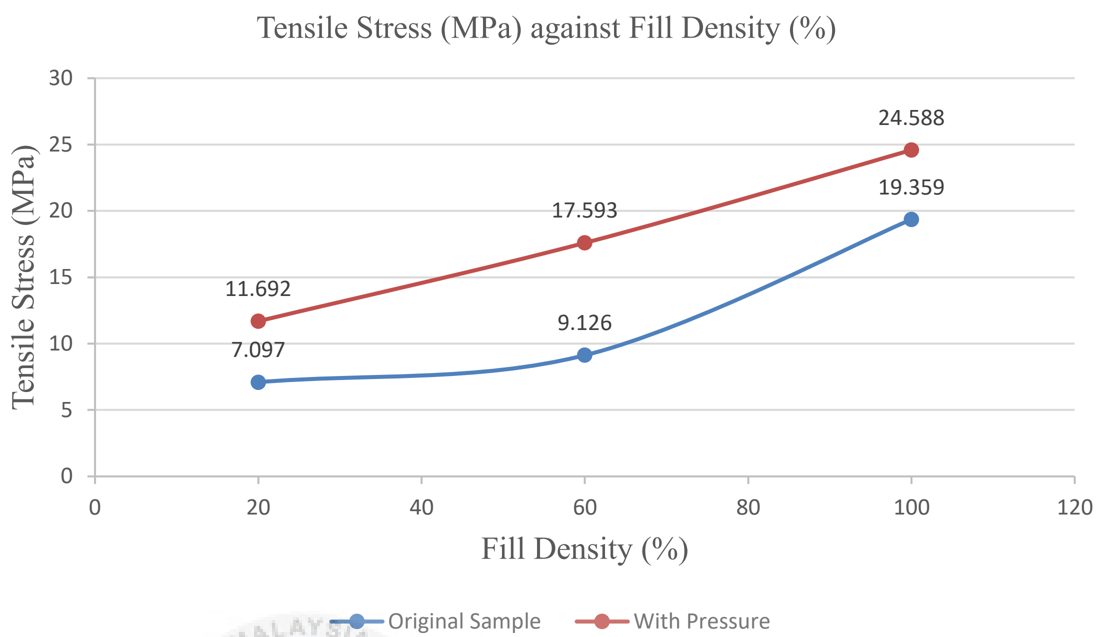


Figure 4.25: Tensile stress against fill density of original sample and sample with pressure

Figure 4.25 shows graph of tensile stress against fill density of original sample and sample with pressure. Tensile stress is the ability of an object to withstand maximum stress while being stretched before breaking. From the graph, it shows that sample with higher fill density have higher tensile stress either original or with pressure sample. This is because sample with higher fill density have more closely arranged filament compared to sample with 20% fill density which is like empty because the filament are loose from each other. Sample with pressure also shows a higher tensile stress compared to the original sample. This is because the filament in sample with pressure were more packed so it can be stretched more compared to original sample before breaking.

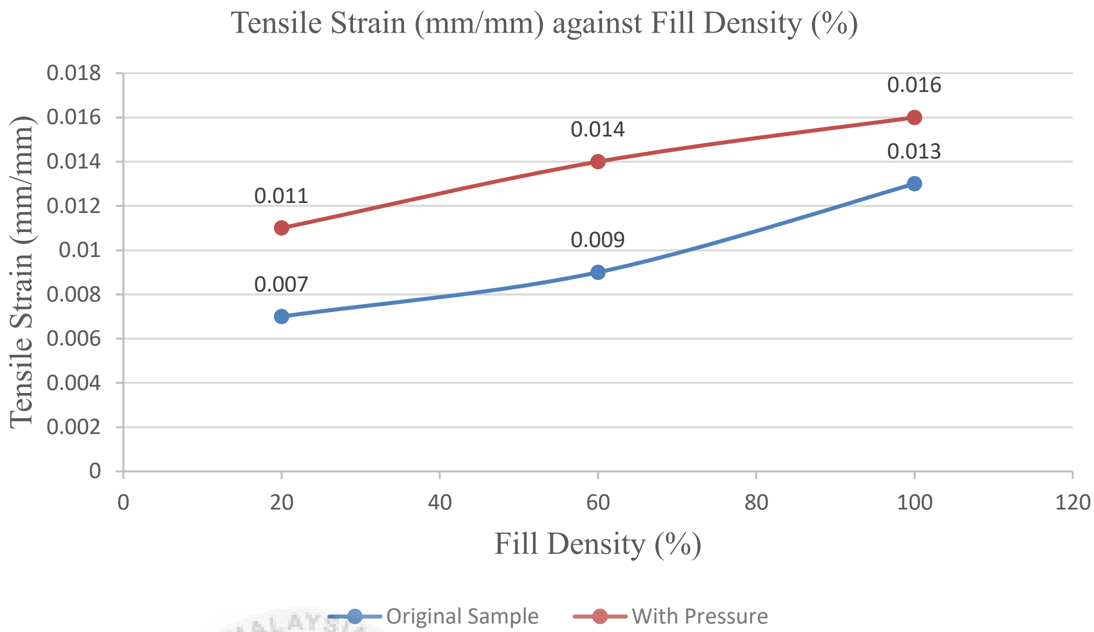


Figure 4.26: Tensile strain against fill density of original sample and sample with pressure

Figure 4.26 shows graph of tensile strain against fill density of original sample and sample with pressure. Tensile strain is the length of deformation shown by object that experienced tensile force. It is shown from the graph that sample with more fill density can be elongate more when subjected to tensile force. Also from the graph, it shows that sample with pressure tensile strain increase linearly as the fill density increase. The graph also shown that sample with pressure perform better under tensile force compared to original sample as it can elongate more.

4.6.6 Porosity Test

Experimental density method was used to obtain the theoretical value for porosity percentage. The formula that were used are as follows:

$$Sample\ Density = \frac{Mass\ of\ Sample}{Volume\ of\ Sample}$$

$$Percentage\ Porosity = \left[1 - \frac{Sample\ Density}{Material\ Density}\right] * (100)$$

$$Material\ Density\ (PLA) = 1.25\ g/cm^3$$

Table 4.7: Porosity Table of Original Sample for Fill Density

Fill Density, (%)	Mass, (g)	Volume, (cm^3)	Density, (g/cm^3)	Porosity, (%)
20	5.717	10.5	0.5445	56.44
60	6.960	10.5	0.6629	46.97
100	9.991	10.5	0.9515	23.88

Table 4.8: Porosity Table of Sample with Pressure for Fill Density

Fill Density, (%)	Mass, (g)	Volume, (cm^3)	Density, (g/cm^3)	Porosity, (%)
20	6.11	10.5	0.5819	53.45
60	9.114	10.5	0.8680	30.56
100	11.086	10.5	1.0558	15.54

Table 4.7 shows the porosity for original sample while Table 4.8 shows the porosity for sample with pressure. Mass of the sample were weigh by using Digital Analytical Balance.

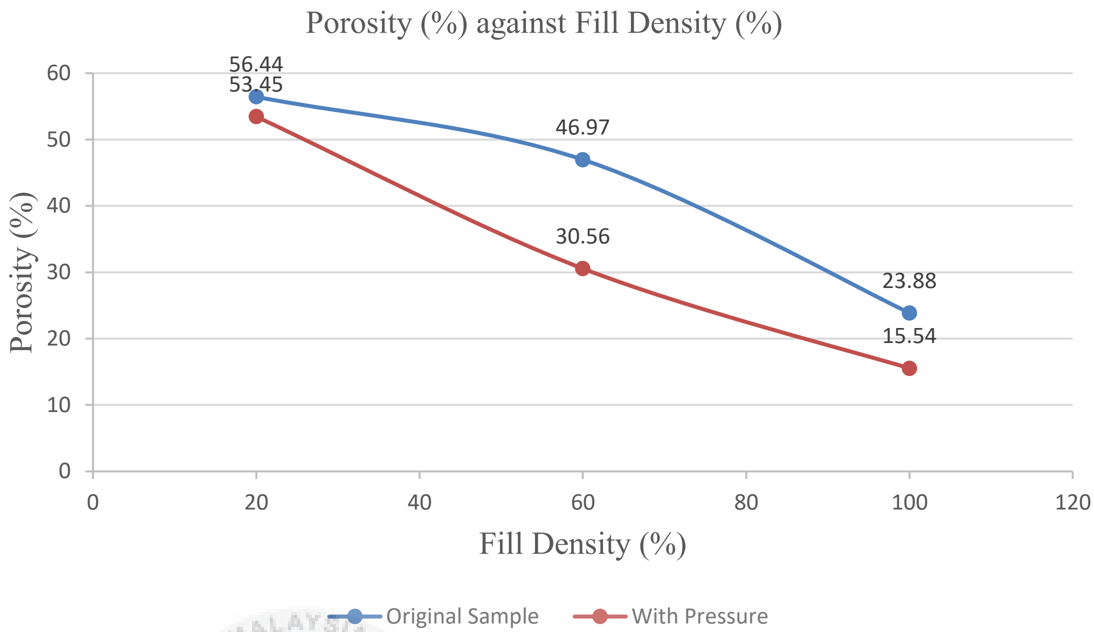


Figure 4.27: Porosity against fill density of original sample and sample with pressure

Based from Figure 4.27, the graph shows the value of porosity decrease as the fill density increase. This is because the fill density affect the mass of the sample, which then affected the porosity of the sample. It is also shown in the graph, that the sample with pressure have a denser porosity compare to their respective class that have a higher porosity. This is due to the effect of applied pressure which reduce the porous area around the filament.

4.7 Effects of Speed

4.7.1 Length

Table 4.9: Length of Original Sample and Sample with Pressure for Speed Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Speed (mm/s)	**Length (mm)**	**Speed (mm/s)**	**Length (mm)**
20	164.6	20	165.0
60	164.5	60	164.9
100	164.6	100	164.9

Based on Table 4.9, it shows both of the samples did not quite reach the actual dimension of the length, which is 165.0 mm. However, the length of sample with pressure is closer to the actual dimension with sample 20 mm/s manage to reach the actual dimension compare to original sample length dimension. The length were measured by using a Vernier caliper.

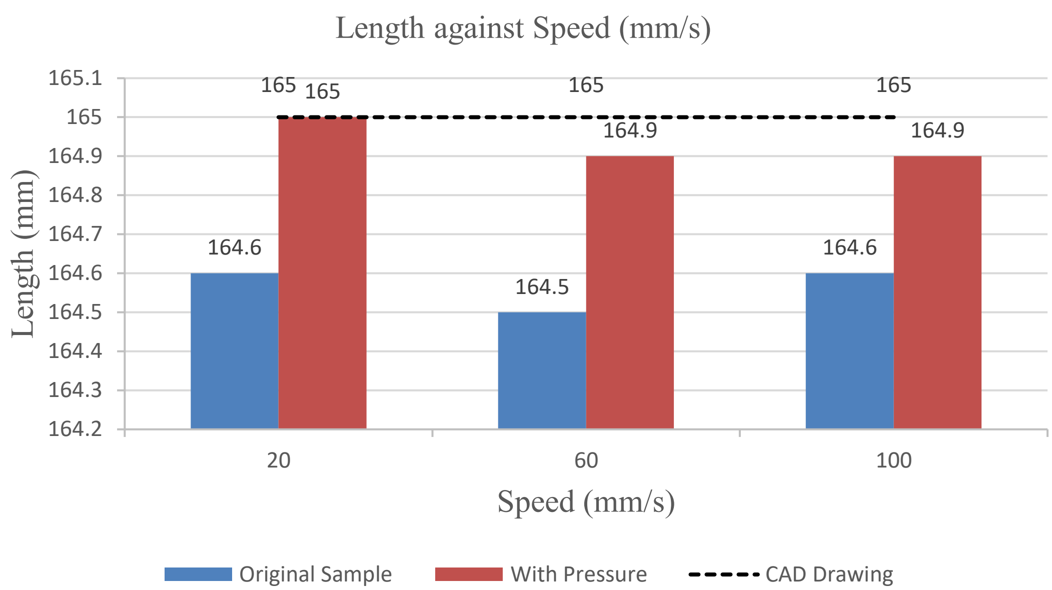


Figure 4.28: Length of original sample and sample with pressure for speed parameter

Figure 4.28 shows the length of the sample plotted against speed parameter. The length for the original sample are range between 164.5 and 164.9. The length of all original sample should be the same as actual dimension, which is 165.0 mm because there is external factor affected the filament during printing process. As for the sample with pressure, the length are 165 mm only for sample at 20% fill density while for fill density 60% and 100%, the length are constant at 164.9 mm. This is because the pressure that were applied to the filament during printing process cause the length of the sample to change and extend it compared to original sample.

4.7.2 Thickness

Table 4.10: Thickness of Original Sample and Sample with Pressure for Speed Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Speed (mm/s)	**Thickness (mm)**	**Speed (mm/s)**	**Thickness (mm)**
20	4.0	20	3.6
60	4.0	60	3.5
100	4.0	100	4.0

Table 4.10 shows the data of the dog bone sample thickness. The thickness of original sample is the same as actual dimension that is 4 mm. As for the sample with pressure, it experienced some decrease in readings of thickness from the actual dimension. The thickness of sample were measured by using a Vernier caliper.

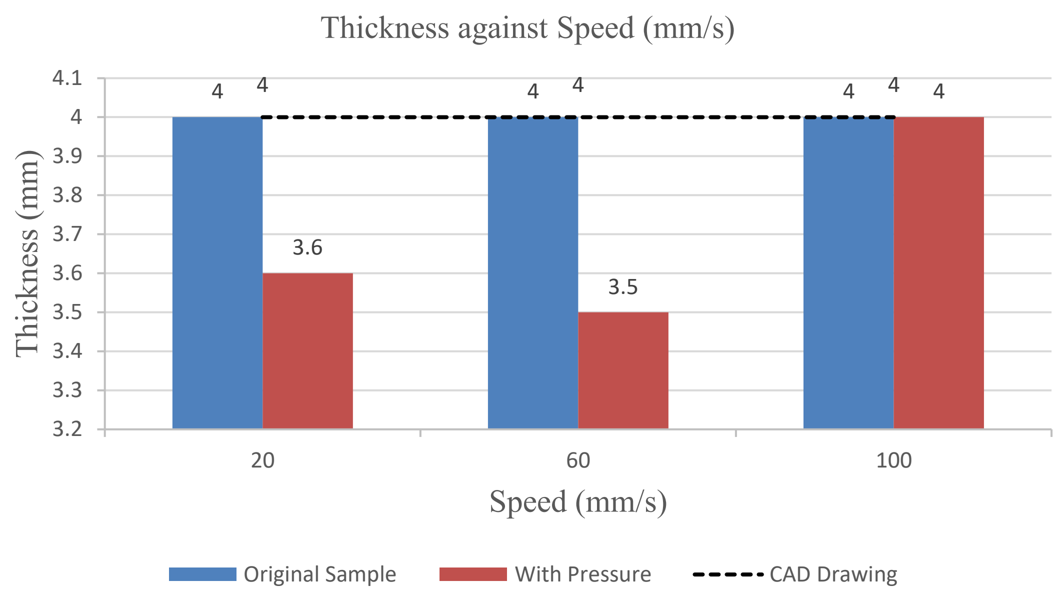


Figure 4.29: Thickness against speed graph of original sample and sample with pressure

Figure 4.29 shows the thickness of the sample plotted against speed parameter. The thickness of original sample are constant at 4.0 mm because there are no pressure applied on it filament while printing. As for the sample with pressure, all the thickness are lower than the one from original sample except the sample that are travel at 100 mm/s while printing because of the pressure that were applied to the filament. This was the effect from the pressure that were applied to the filament during printing process and it cause the thickness of the sample to be slightly reduce from the actual dimension.

4.7.3 Width

Table 4.11: Width of Original Sample and Sample with Pressure for Speed Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Speed (mm/s)	**Width (mm)**	**Speed (mm/s)**	**Width (mm)**
20	18.8	20	19.3
60	18.8	60	19.3
100	19.0	100	19.1

From Table 4.11, it shows the width of original dog bone sample and dog bone sample with pressure that were measured by using a Vernier caliper. The width of dog bone sample with pressure shows some increasing in number from actual dimension compared to original dog bone sample.

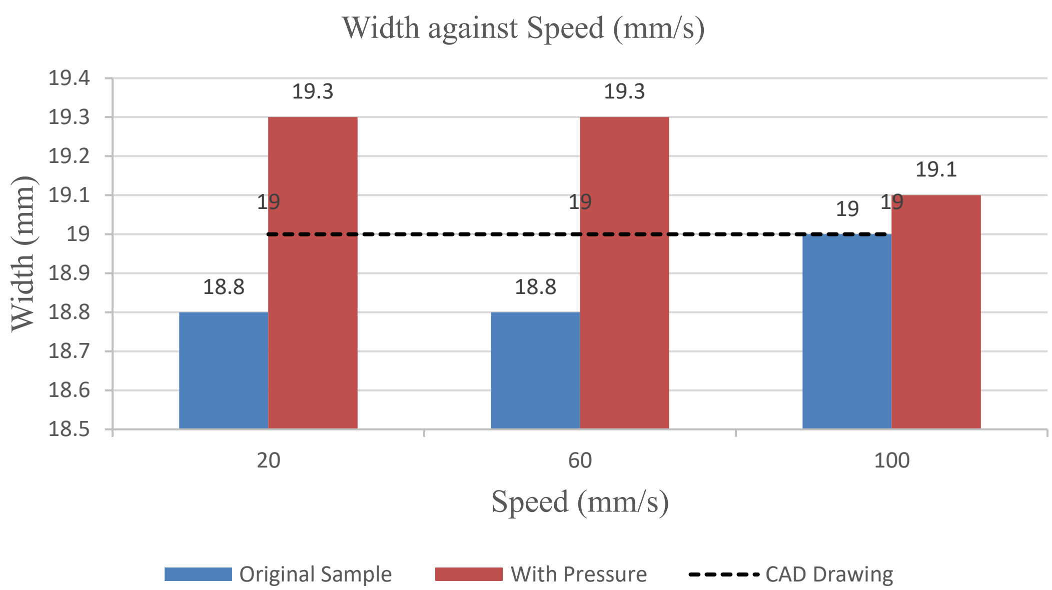


Figure 4.30: Width against speed graph of original sample and sample with pressure

Figure 4.30 shows the width of the sample plotted against speed parameter. The width of original sample are range between 19.0 mm and 18.8 mm. The width of original sample with speed parameter 20mm/s and 60mm/s appeared to be slightly short from actual dimension of the width, which is 19.0 mm. As for the sample with pressure, the width are larger from actual dimension because of the pressure that were applied to the filament. The pressure applied cause the filament to spread and as a result the width increase.

4.7.4 Surface Roughness

Table 4.12: Surface Roughness of Original Sample and Sample with Pressure for Speed Parameter

ORIGINAL SAMPLE		SAMPLE WITH PRESSURE	
Speed, (mm/s)	**Surface Roughness, (µm)**	**Speed, (mm/s)**	**Surface Roughness, (µm)**
20	1.2513	20	1.1874
60	1.6873	60	1.5726
100	2.2743	100	1.9307

Table 4.12 shows the surface roughness of all the samples, original and with pressure. The reading of the surface roughness was taken three times and the average reading was recorded in the table above. The data that were recorded were then used for analysed.

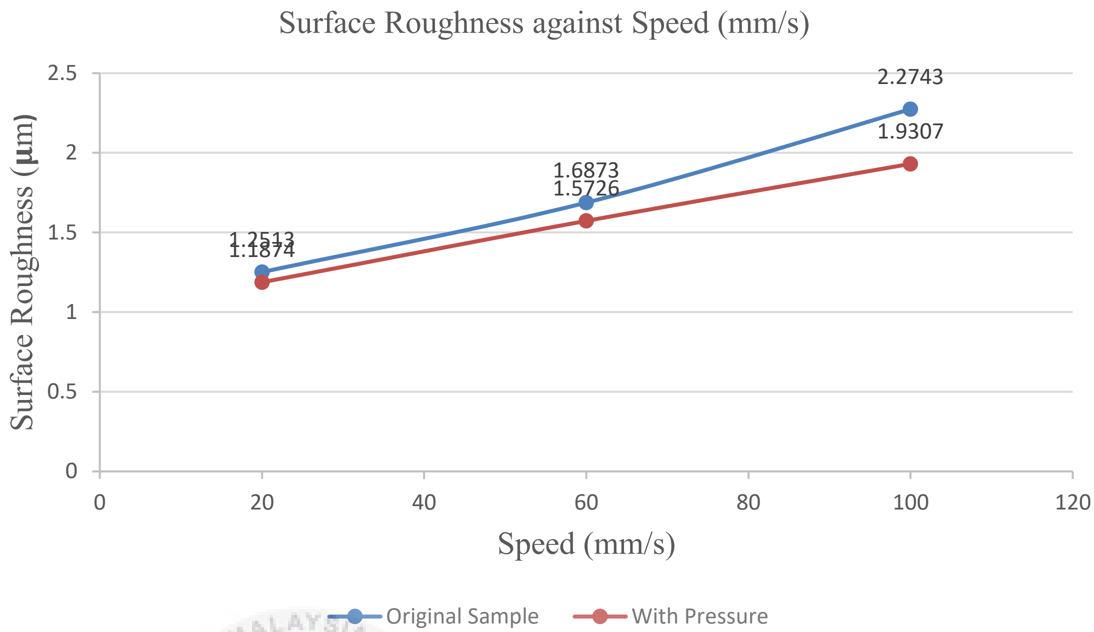


Figure 4.31: Surface roughness against speed graph of original sample and sample with pressure

Figure 4.31 shows the graph of surface roughness against speed. The graph a shows an increase in the value of surface roughness readings as the value of speed increasing. Figure above also shows that the sample with pressure have smaller reading of surface roughness compared to original sample. However, it is not noticeable because there is just a slight different in surface roughness between original sample and sample with pressure. The original sample readings is between 1.2513 and 2.2743 while the readings of sample with pressure is range between 1.1874 and 1.9307. The surface roughness increase when the printing speed increase is because the filament deposited at higher speed is uneven compared to a lower speed.

4.7.5 Tensile Test

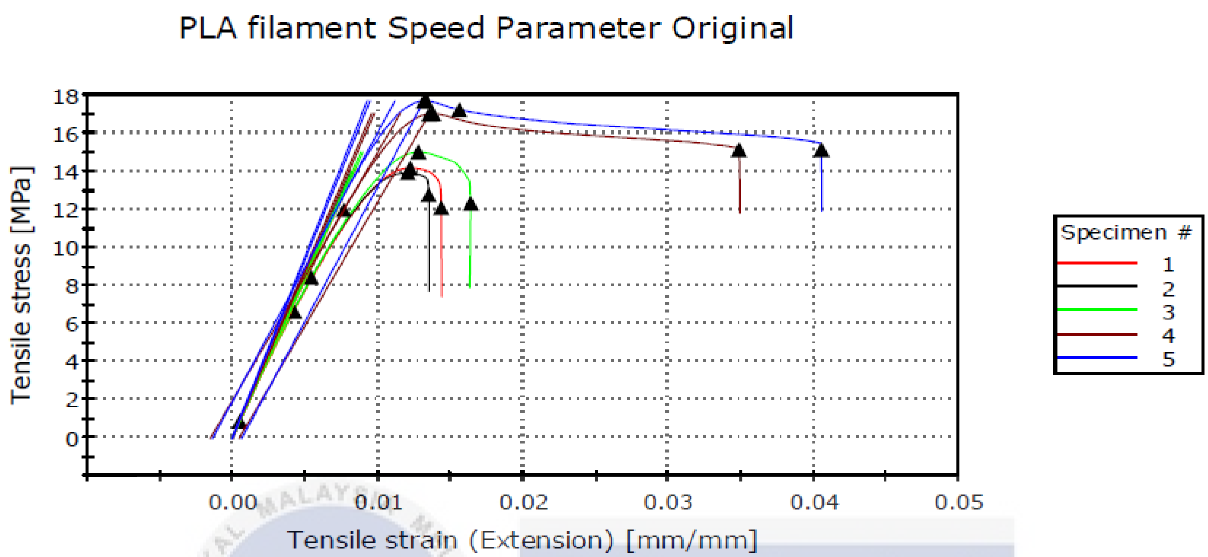


Figure 4.32: Tensile test graph of the original sample for speed parameter from Universal Testing Machine (UTM) Instron 8872

Figure 4.32 shows the graph of tensile stress against tensile strain, of the original dog bone sample. Specimen 1, 3, and 5 is original sample with speed 20mm/s, 60mm/s, and 100mm/s respectively. The maximum load that can be withstand by the sample is increase as the speed of the sample while printing is increase.

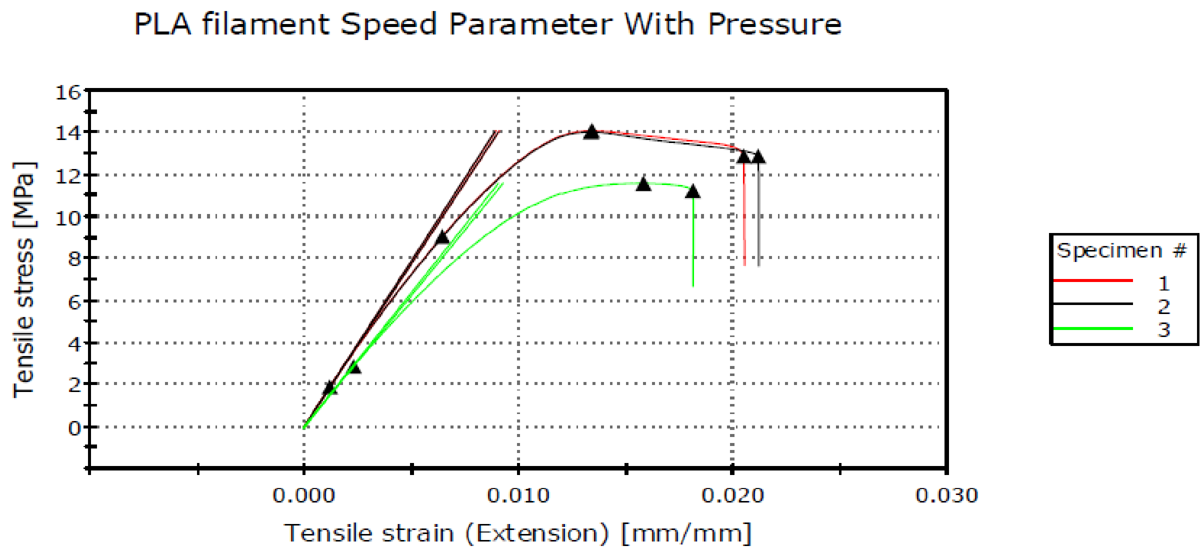


Figure 4.33: Tensile test graph of the sample with pressure for speed parameter from Universal Testing Machine (UTM) Instron 8872

Figure 4.33 shows the graph of tensile stress against tensile strain, of the dog bone sample with pressure. Specimen 1, 2, and 3 is sample with pressure for speed parameter of 20mm/s, 60mm/s, and 100mm/s respectively. The maximum load that can be withstand by the sample with pressure is decreasing while the speed is increasing.

Table 4.13: Tensile Test of Original Sample for Speed Parameter

Original Sample (Speed)	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]	Load at Break (Standard) [N]
20	1064.338	14.153	0.012	1655.603	907.819
60	1127.098	14.988	0.013	1660.599	925.581
100	1328.475	17.666	0.013	1857.418	1137.002

Table 4.14: Tensile Test of Sample with Pressure for Speed Parameter

Original Sample (Speed)	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]	Load at Break (Standard) [N]
20	1069.770	14.076	0.013	1541.518	977.479
60	1054.497	14.023	0.013	1543.928	966.874
100	871.370	11.587	0.016	1244.518	844.780

Table 4.13 shows the tensile test data for original sample while Table 4.14 shows the tensile test for sample with pressure. The graph analysis was consist of maximum load, tensile stress, and tensile strain.

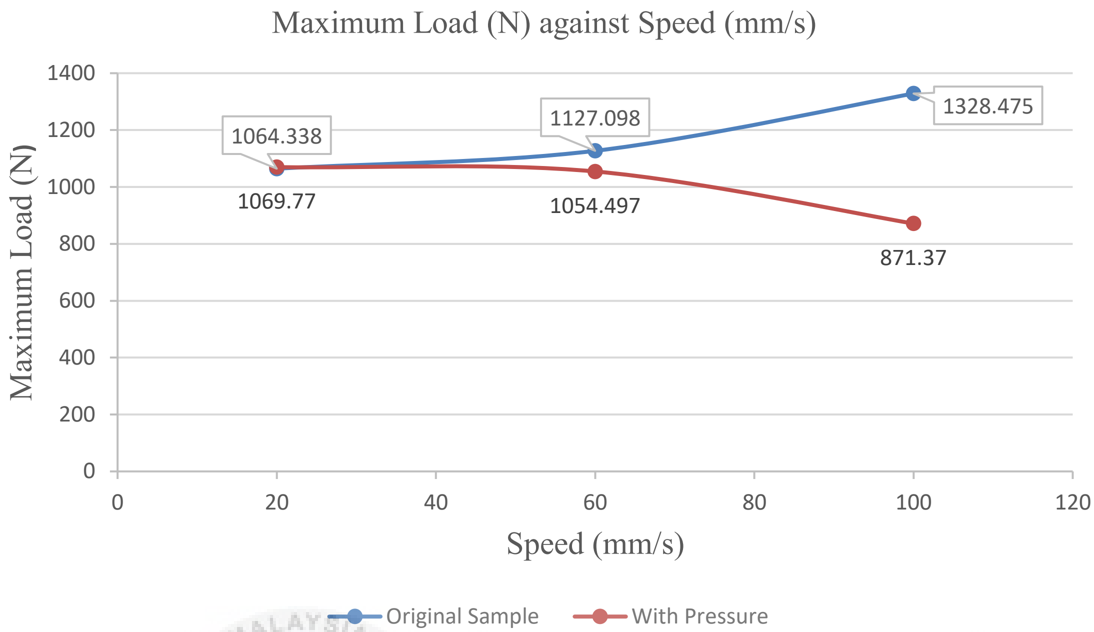


Figure 4.34: Maximum load against speed of original sample and sample with pressure

Figure 4.34 shows the graph of maximum load against speed parameter. From the pattern of the graph, it shows that the maximum load for the original sample increase as the speed increase. The sample with pressure shows a declining pattern of maximum load as the speed parameter increase.

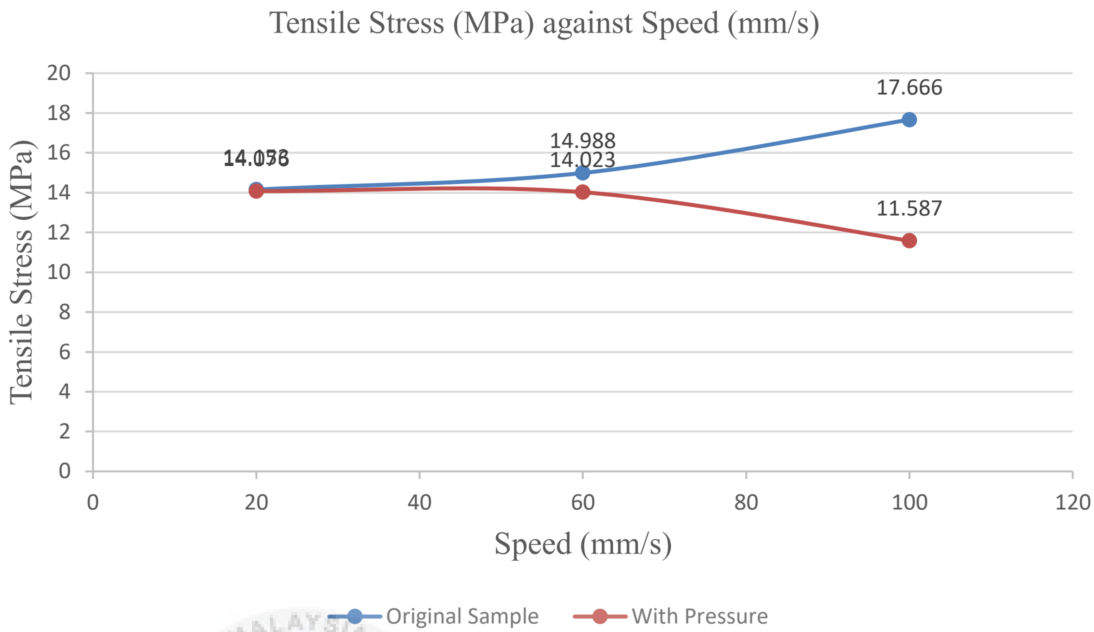


Figure 4.35: Tensile stress against speed of original sample and sample with pressure

Figure 4.35 shows the graph of tensile stress against speed parameter. From the pattern of the graph, it shows that the tensile stress for the original sample increase as the speed increase. The sample with pressure experienced a decrease in the value of tensile stress compared to speed parameter.

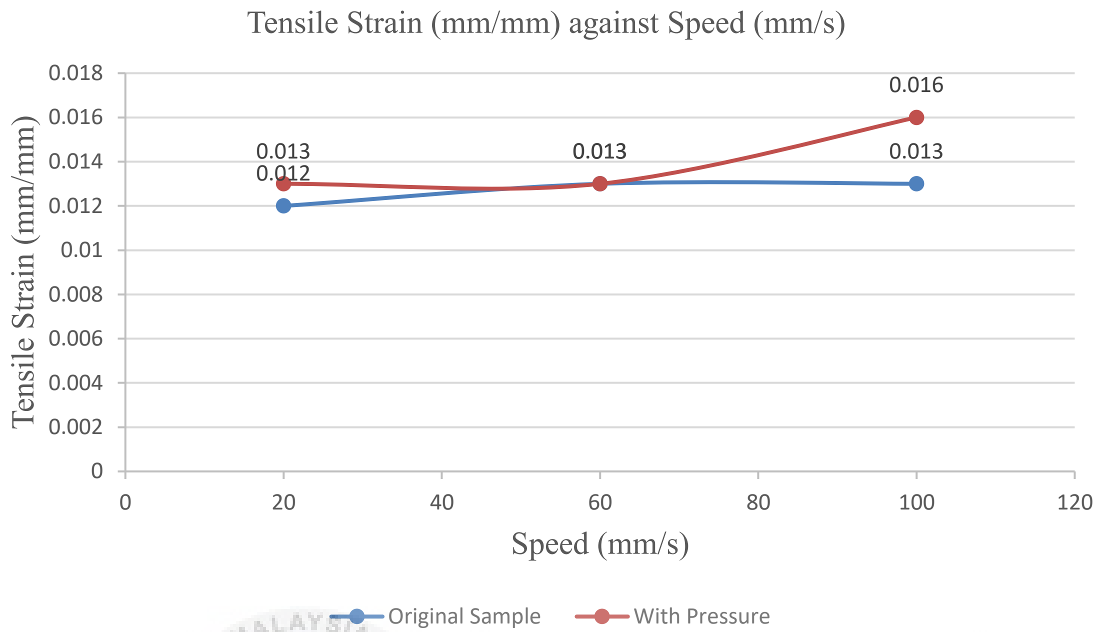


Figure 4.36: Tensile strain against speed of original sample and sample with pressure

Figure 4.36 shows graph of tensile strain against speed of original sample and sample with pressure. The original sample pattern from the graph of tensile strain against speed shows the extension experienced were between 0.012 and 0.013. As for the sample with pressure, the extension were range from 0.013 to 0.016. The sample with pressure happens to have a longer extension, despite have a lower tolerance for tensile stress.

4.7.6 Porosity Test

Experimental density method was used to obtain the theoretical value for porosity percentage. The formula that were used are as follows:

$$Sample\ Density = \frac{Mass\ of\ Sample}{Volume\ of\ Sample}$$

$$Percentage\ Porosity = \left[1 - \frac{Sample\ Density}{Material\ Density}\right] * (100)$$

$$Material\ Density\ (PLA) = 1.25\ g/cm^3$$

Table 4.15: Porosity Table of Original Sample for Speed Parameter

Speed, (mm/s)	Mass, (g)	Volume, (cm^3)	Density, (g/cm^3)	Porosity, (%)
20	6.732	10.5	0.6411	48.71
60	7.023	10.5	0.6688	46.50
100	7.654	10.5	0.7290	41.68

Table 4.16: Porosity Table of Sample with Pressure for Speed Parameter

Speed, (mm/s)	Mass, (g)	Volume, (cm^3)	Density, (g/cm^3)	Porosity, (%)
20	7.542	10.5	0.7183	42.54
60	7.416	10.5	0.7063	43.5
100	7.058	10.5	0.6722	46.22

Table 4.15 shows the porosity for original sample and Table 4.16 shows the porosity for sample with pressure. Mass of the sample were weigh by using Digital Analytical Balance.

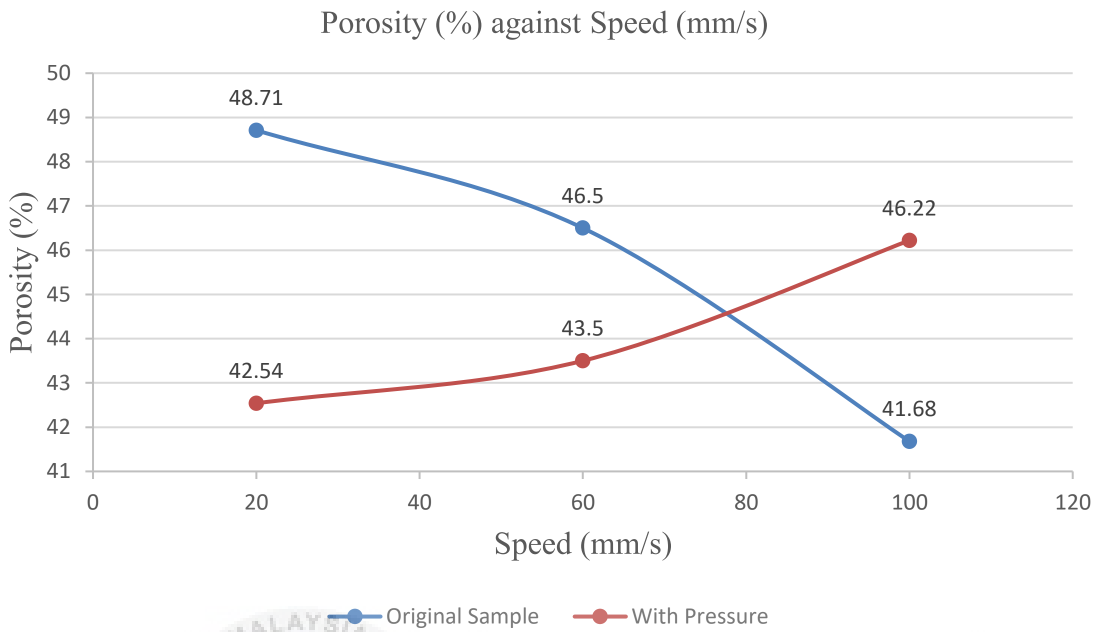


Figure 4.37: Porosity against speed parameter of original sample and sample with pressure

Based from Figure 4.37, the graph shows the value of porosity did not show the same pattern as Figure 4.27. This is because for both original sample and sample with pressure, only the speed were changed but the fill density were kept constant at 20% fill density. The pattern from the graph above also shows that when pressure were applied, the porosity are improved when the sample are printed at lower speed compared to higher speed.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this project, pressing mechanism were design as the new mechanism during 3D printing thus the first objective is achieve. The pressing mechanism was fabricate as additional mechanism to integrate to the existing 3D printer and improve the mechanical properties of the printed object. Finish fabricating the pressing mechanism and attach it to the existing 3D printer answered the second objective of this project. Sixteen dog bone samples were printed to undergo experiments. Two parameters were chosen for this experiment, which is infill density and travel speed during printing. Eight samples were used for infill density experiment and another eight samples were used for speed experiment. To test the effectiveness of the mechanism, the results obtained from the experiment were compared. Length, thickness, width, surface roughness, tensile test and porosity test were recorded for all sixteen samples. The result of the experiments conducted were analysed for its effectiveness to complete the third objective for this project.

The samples with pressure works the best for infill density parameter when compared to the original samples. This is because the results for tensile test and porosity test show that the sample with applied pressure able to withstand higher tensile stress compared to original samples, and it improve the percentage of porosity for the sample with applied pressure. The only downside of the pressing mechanism is that it affect the actual dimension slightly for thickness and width of the dog bone samples. As for the sample of speed parameter, the applied pressure did not improved the tensile test result when compared to original samples. However, sample with pressure applied in speed parameter does improve the percentage of porosity of the dog bone sample at lower speed when compare to original sample. Surface roughness quality depends on the infill density and travel speed choose when printing. The samples with pressure does improve the surface roughness but it is more related by it chosen parameter.

5.2 Recommendation

To improve the accuracy for the measured length, thickness and width, digital ruler and digital Vernier caliper could be used to get a more accurate result. As for future research, instead of testing for two different parameters it will be better if the results compared are the analysis of infill density parameter between two materials such as PLA and ABS.

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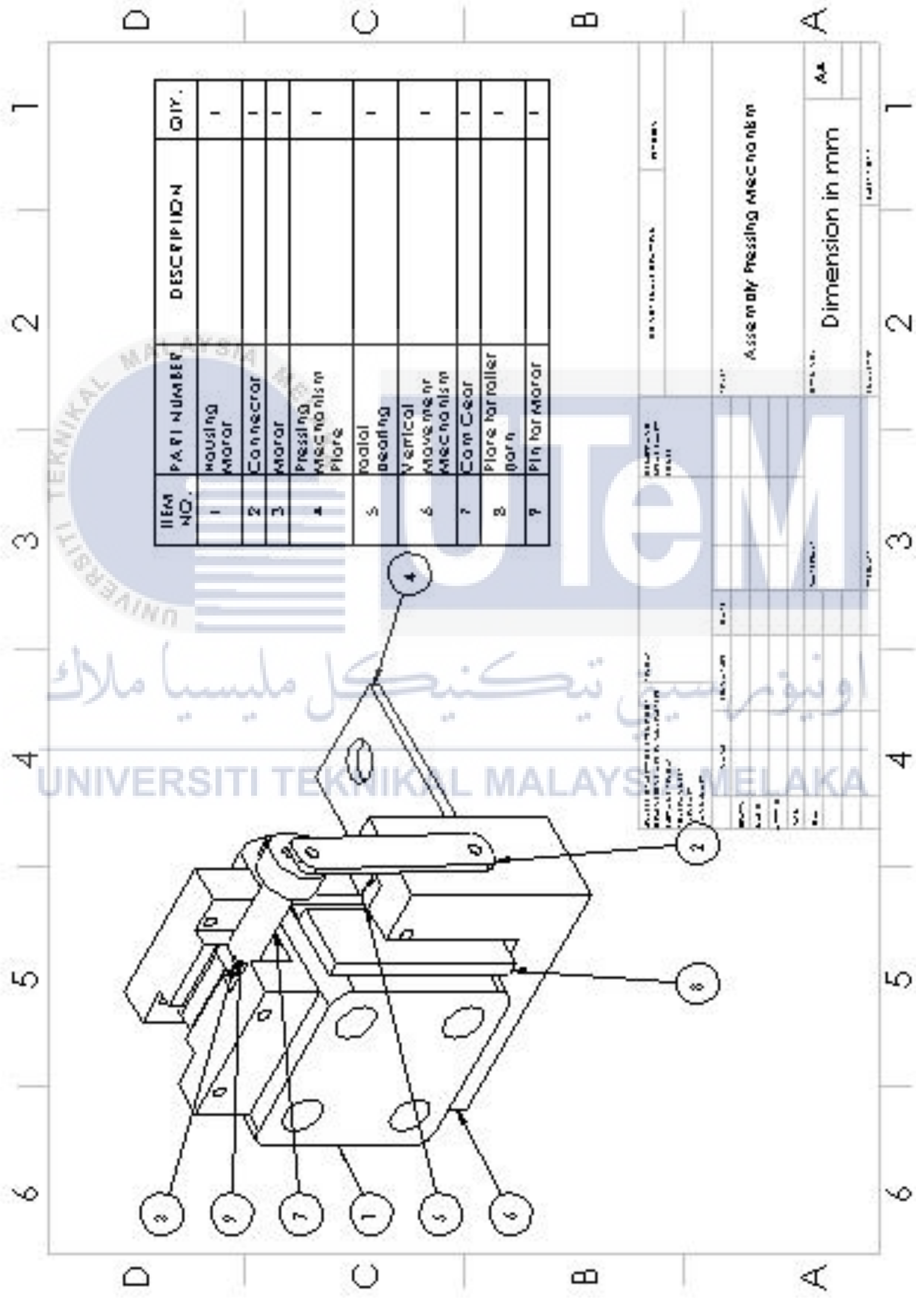
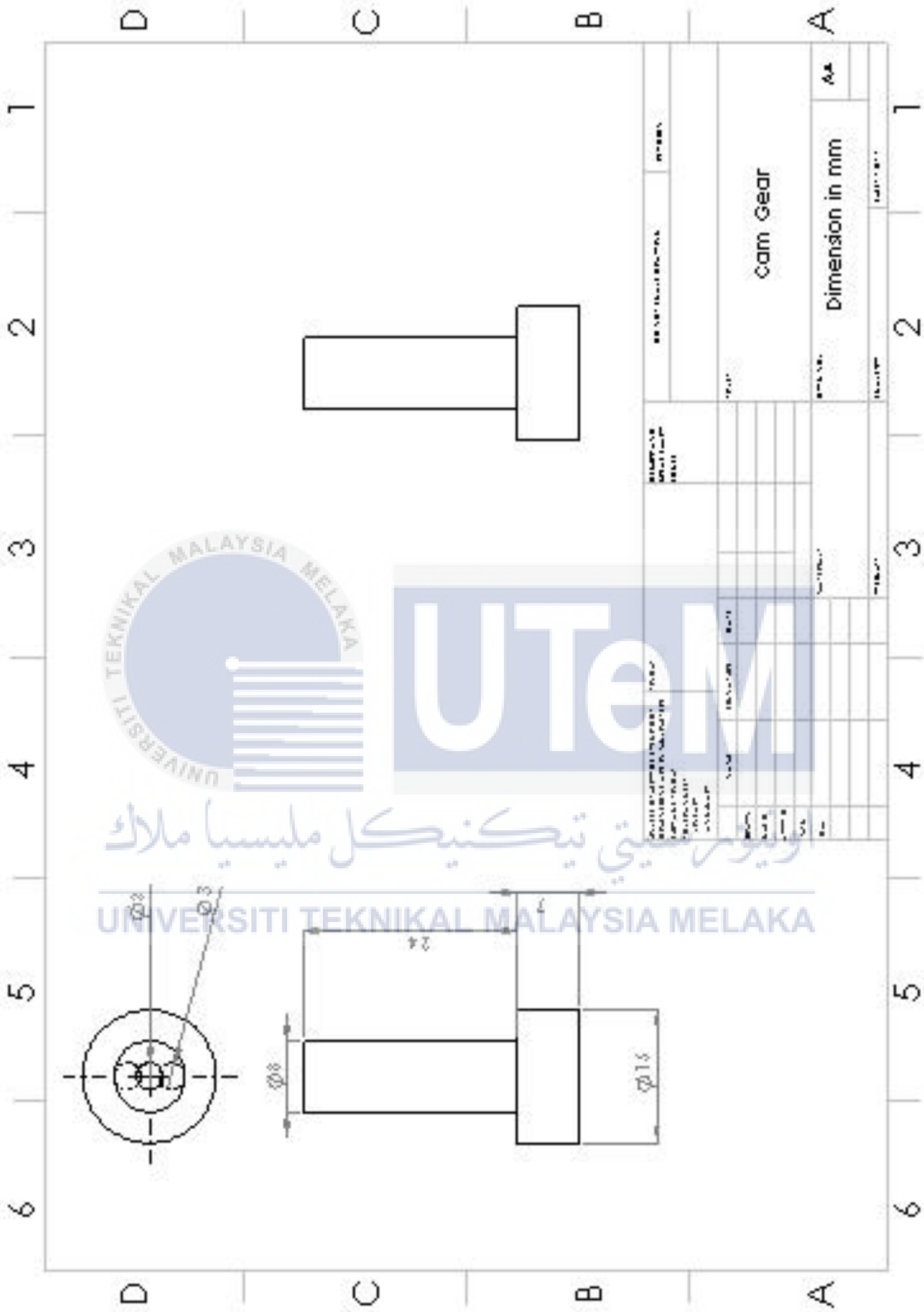
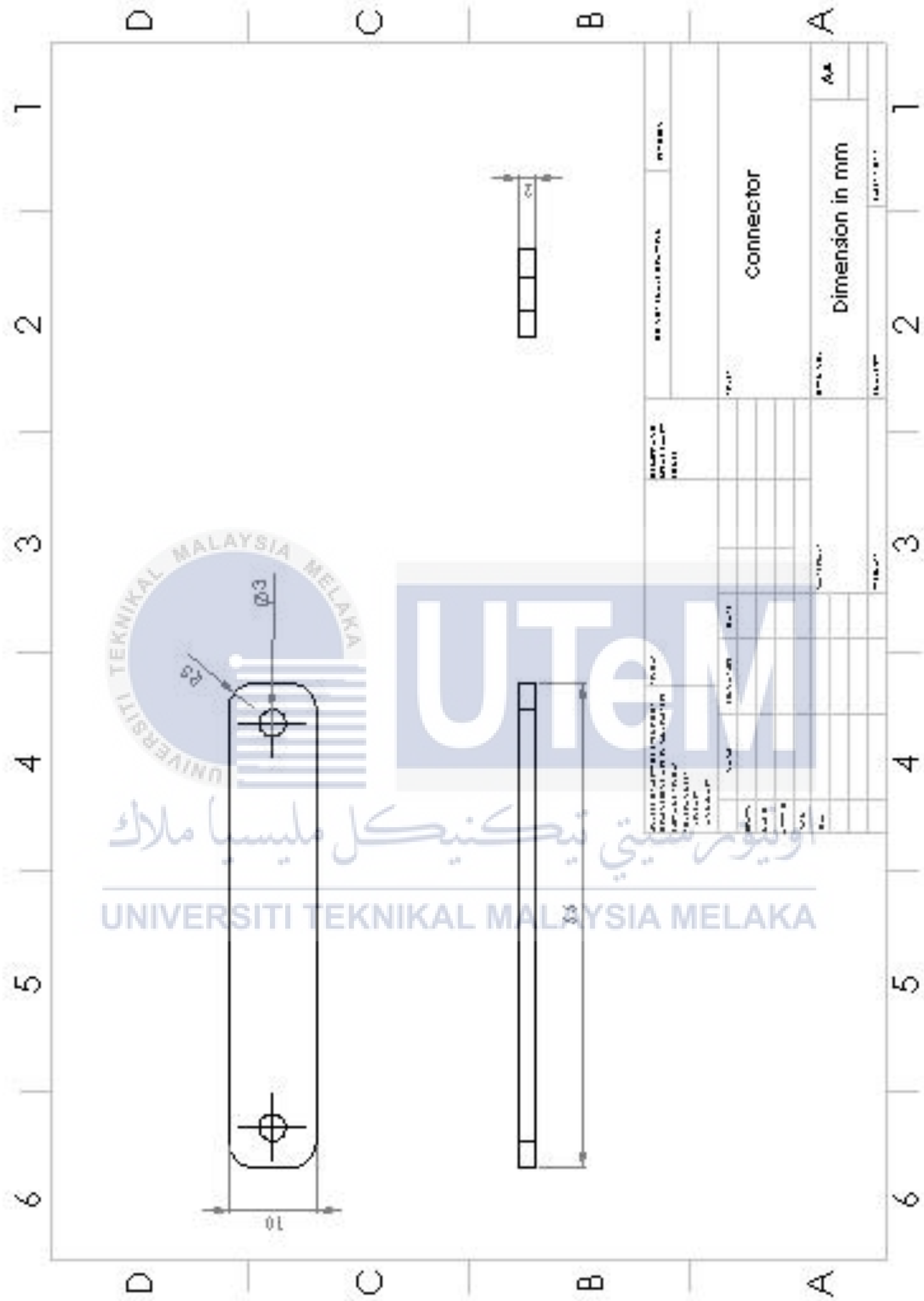
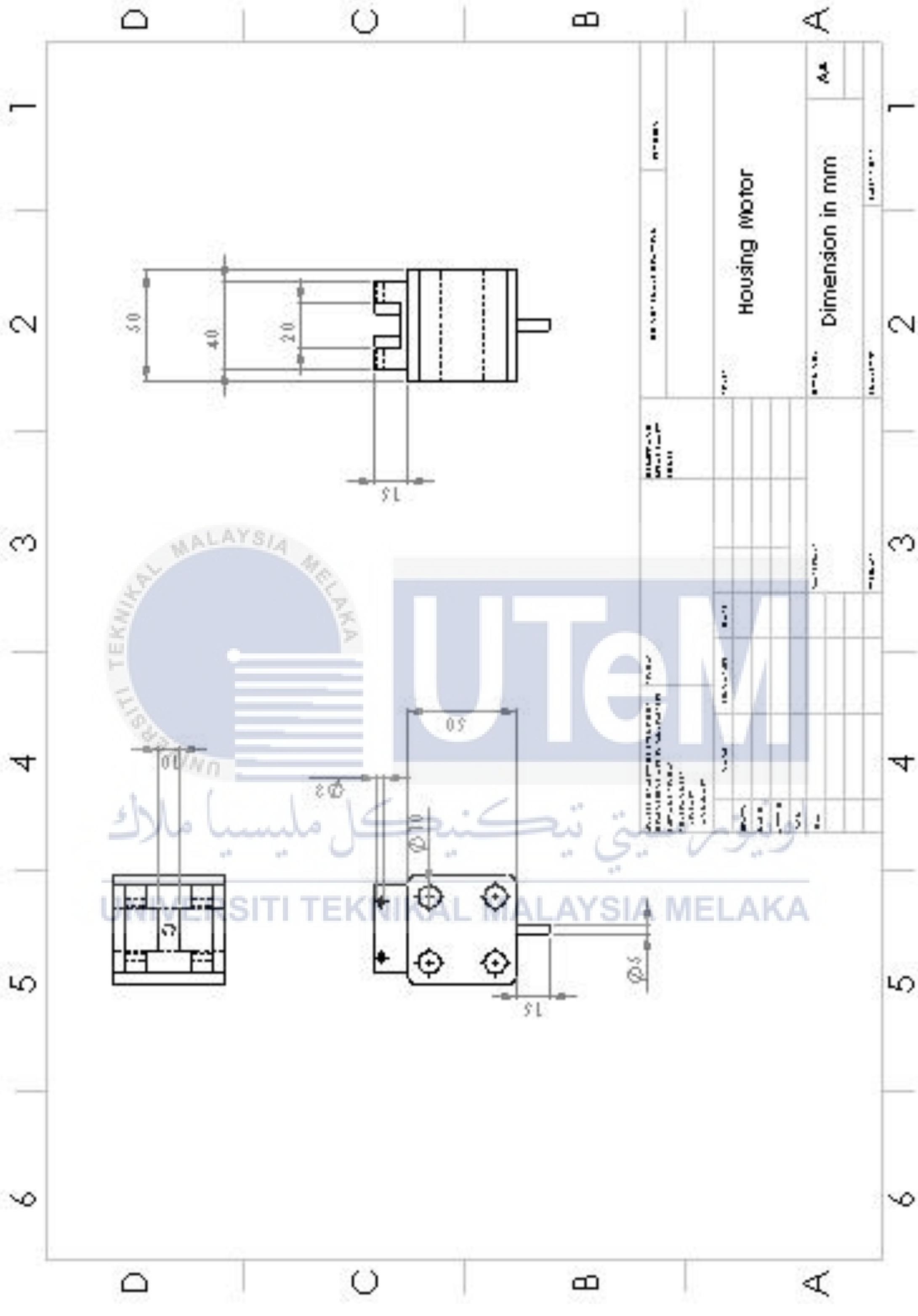
APPENDIX



ITEM NO.
PART NUMBER
DESCRIPTION
QTY.
1 Housing Motor 1
2 Connector 1
3 Motor 1
4 Pressing Mechanism Plate 1
5 radial bearing 1
6 Vertical Movement Mechanism 1
7 Cam Gear 1
8 Plate for roller barn 1
9 Pin for Motor 1
Assembly Pressing Mechanism
Dimension in mm
A4


Cam Gear
Dimension in mm


Connector
Dimension in mm
Ø3
R5
10


Housing Motor
Dimension in mm

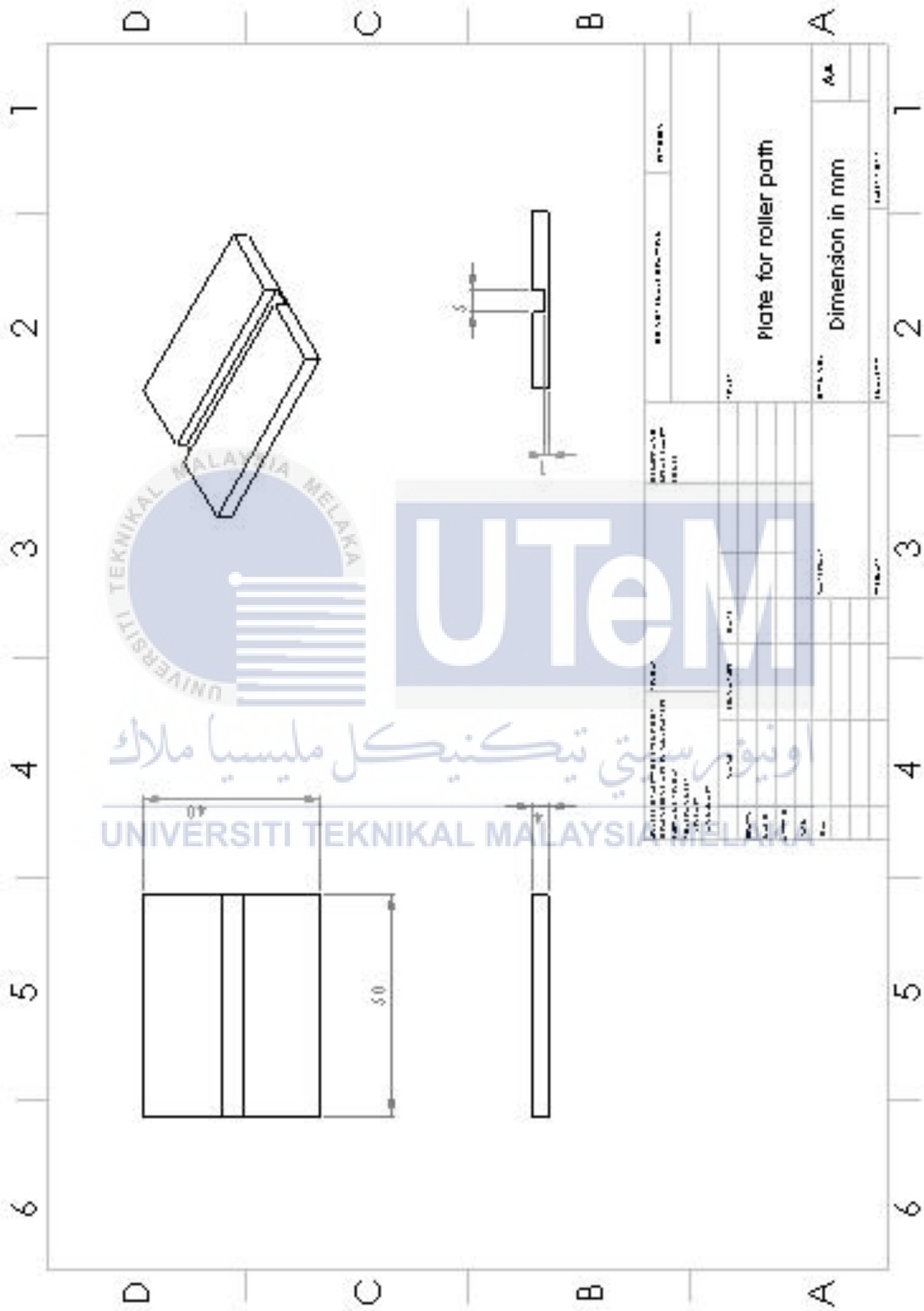
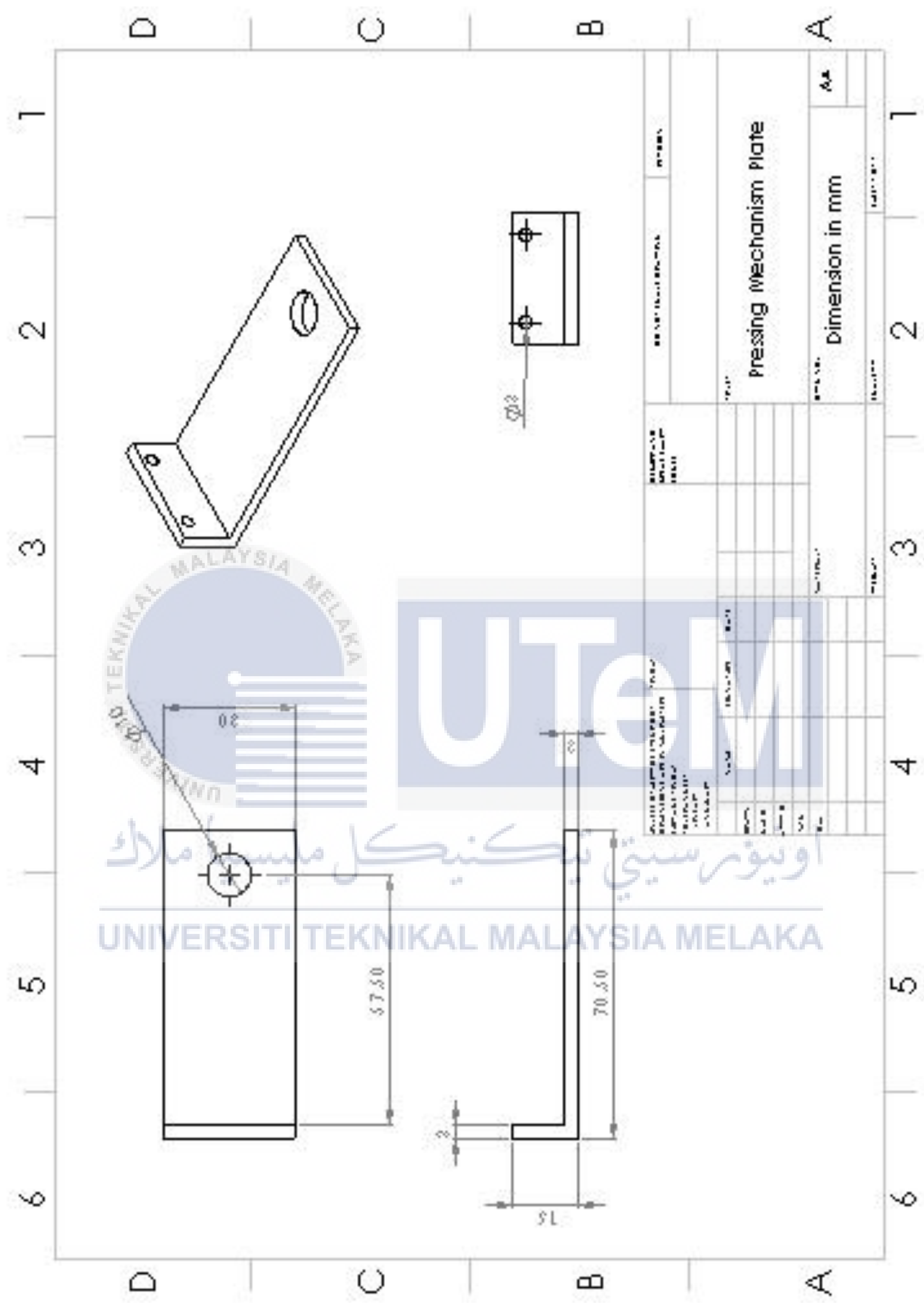
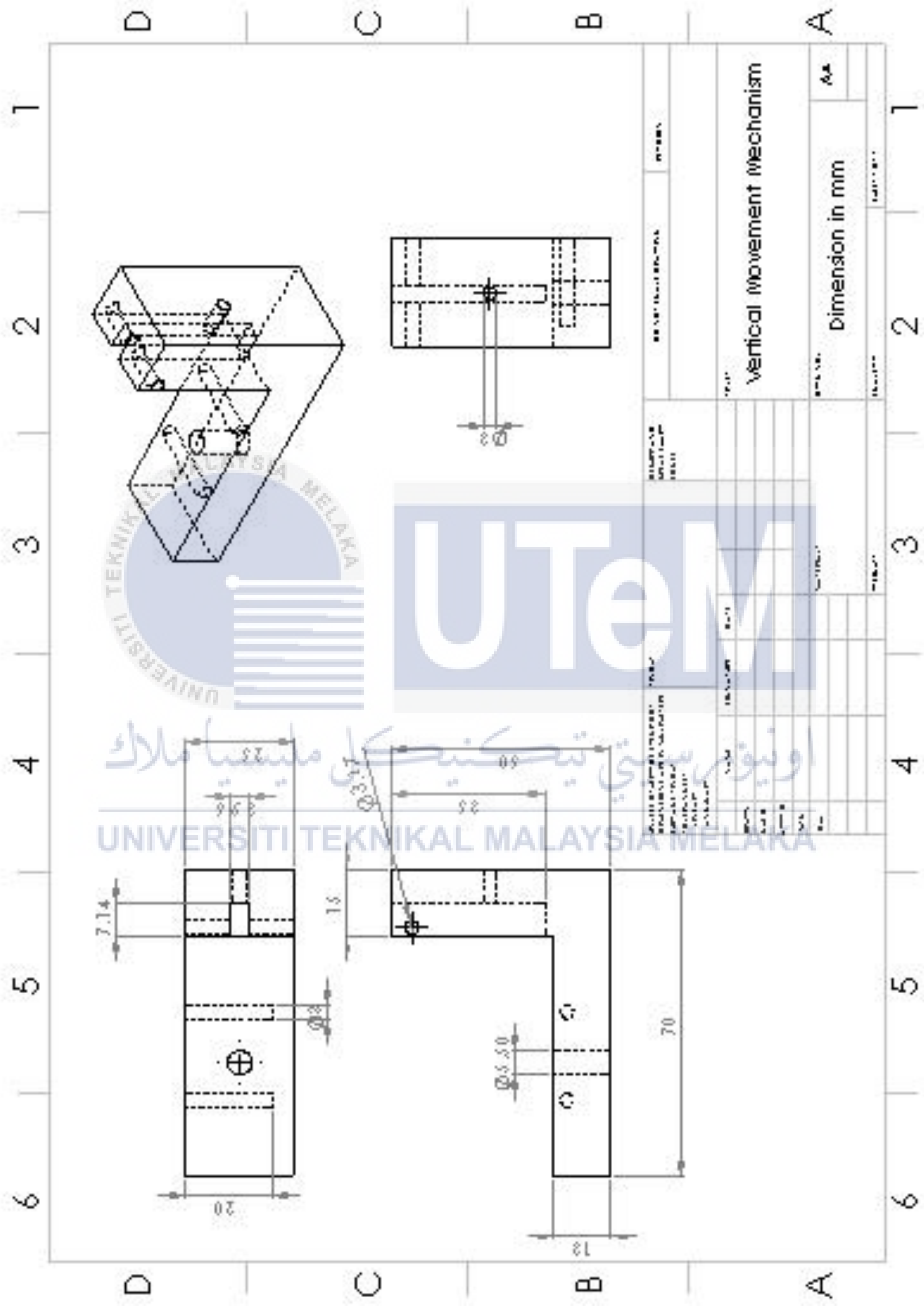
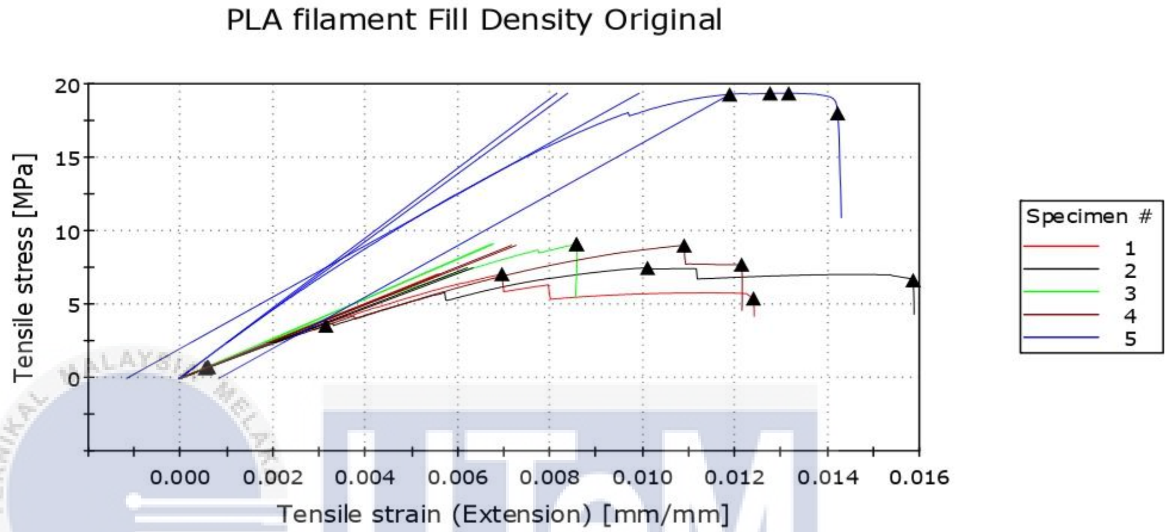


Plate for roller path
Dimension in mm
A4
40
50
5
1
4


Pressing Mechanism Plate
Dimension in mm
A4
UNIVERSITI TEKNIKAL MALAYSIA MELAKA


Vertical Movement Mechanism
Dimension in mm

Tensile Test for PLA

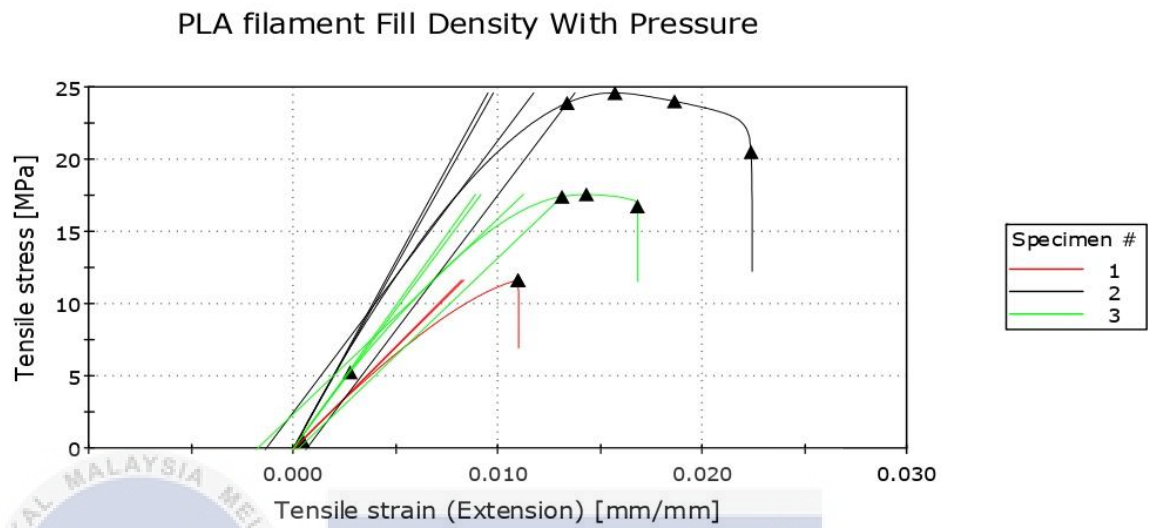


	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	539.396	7.097	0.007
2	571.436	7.519	0.010
3	693.610	9.126	0.009
4	687.367	9.044	0.011
5	1471.316	19.359	0.013

	Load at Yield (Offset 0.2 %) [N]	Tensile stress at Yield (Offset 0.2 %) [MPa]	Load at Break (Standard) [N]
1	-----	-----	413.864
2	-----	-----	507.674
3	-----	-----	693.610
4	-----	-----	588.132
5	1465.718	19.286	1369.239

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]
1	1257.353	-----
2	1185.540	-----
3	1345.234	-----
4	1242.137	-----
5	2300.171	1746.339

Tensile Test for PLA

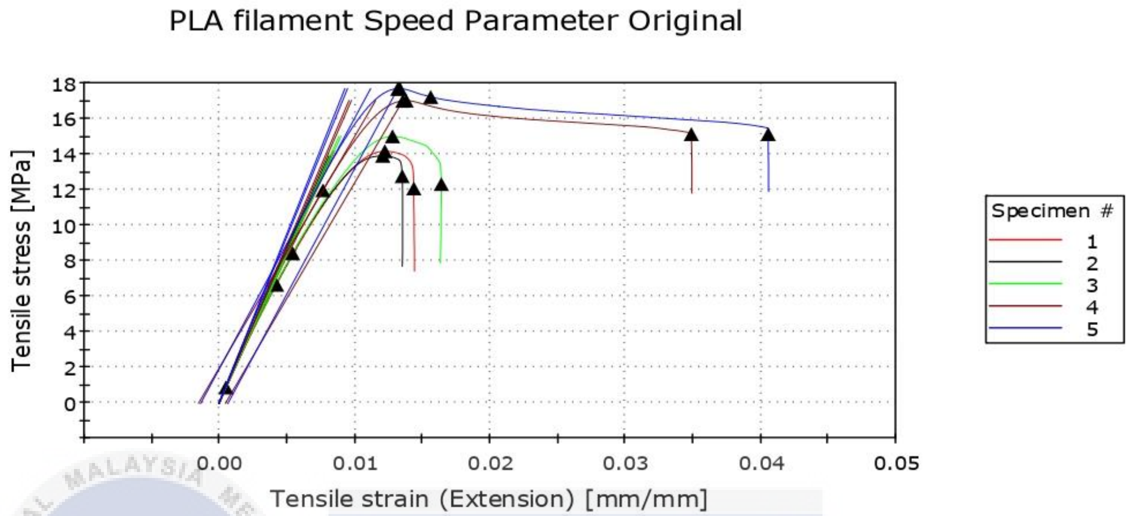


	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	888.575	11.692	0.011
2	1868.724	24.588	0.016
3	1337.065	17.593	0.014

	Load at Yield (Offset 0.2 %) [N]	Tensile stress at Yield (Offset 0.2 %) [MPa]	Load at Break (Standard) [N]
1	-----	-----	888.575
2	1816.010	23.895	1559.599
3	1325.501	17.441	1273.689

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]
1	1398.509	-----
2	2503.675	1874.235
3	1908.275	1349.798

Tensile Test for PLA

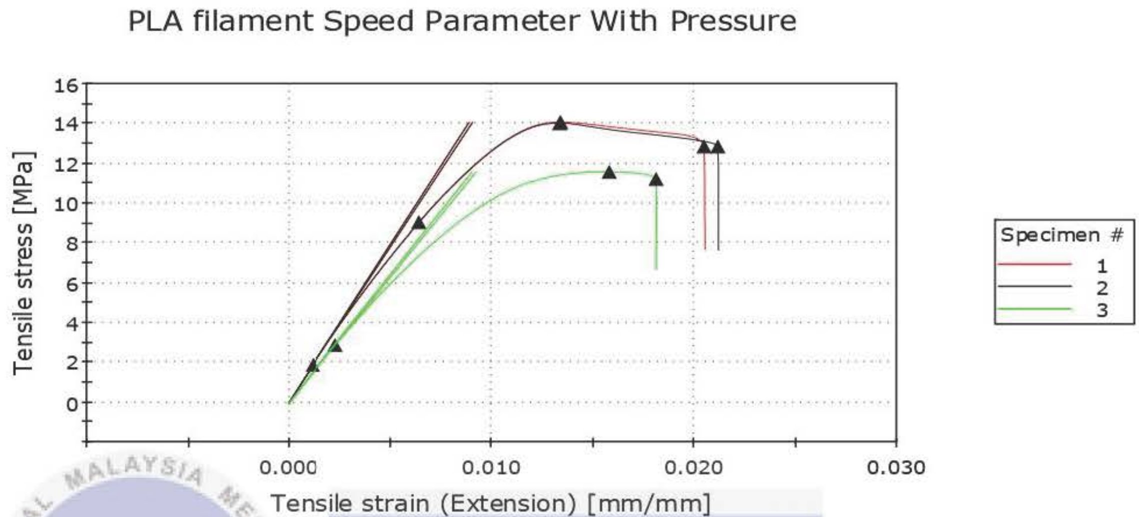


	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	1064.338	14.153	0.012
2	1045.164	13.898	0.012
3	1127.098	14.988	0.013
4	1277.926	16.994	0.014
5	1328.475	17.666	0.013

	Load at Yield (Offset 0.2 %) [N]	Tensile stress at Yield (Offset 0.2 %) [MPa]	Load at Break (Standard) [N]
1	-----	-----	907.819
2	-----	-----	960.266
3	-----	-----	925.581
4	1277.011	16.982	1136.893
5	1327.920	17.659	1137.002

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]
1	1655.603	-----
2	1680.521	-----
3	1660.599	-----
4	1734.740	1299.437
5	1857.418	1409.743

Tensile Test for PLA



	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	1069.770	14.076	0.013
2	1054.497	14.023	0.013
3	871.370	11.587	0.016

	Load at Yield (Offset 0.2 %) [N]	Tensile stress at Yield (Offset 0.2 %) [MPa]	Load at Break (Standard) [N]
1	-----	-----	977.479
2	-----	-----	966.874
3	-----	-----	844.780

	Modulus (Automatic) [MPa]	Modulus (E-modulus) [MPa]
1	1541.518	-----
2	1543.928	-----
3	1244.518	-----