MECHANICAL PROPERTIES OF COMPONENTS FABRICATED VIA LOW COST ADDITIVE MANUFACTURING

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DECLARATION

I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledge.

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SUPERVISOR DECLARATION

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

Signature : ……………………………………

Name : Ir. Dr. Mohd Rizal Bin Alkahari

Date : ……………………………………

DEDICATION

My beloved mother and father

My dearest siblings

ACKNOWLEDGEMENT

First and foremost, praised to Allah S.W.T for giving the opportunity and seeing through a truly difficulties during completing the final year project as well as the technical report.

A highly gratitude to my Final Year Project's Supervisor, Dr. Ir. Mohd Rizal Alkahari for the continuous support and give me a guidance throughout this project until it is done.

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ABSTRACT

The aim of this research is to study about the mechanical properties of acrylonitrile butadiene stryrene (ABS) which is widely used in 3D printing. The technique being used in this research is fused deposition modelling (FDM). It is widely known that the product made by open source 3D printer facing some problems related to the strength of the product. The current open source 3D printer can be improved in order to produce good quality of product. Based on the study, it is found that by applying pressure on the printed product, may enhance the quality of the product. Thus, the mechanical properties of ABS can be improved after applying the pressure on the ABS while printing the part. The roller is designed and installed to the nozzle of the printer. The design of the roller is selected through several stages including morphological chart and conceptual design. In order to determine the strength of the samples, there are several experiments are tested to determine the strength of the existing printed part as well by applying pressure using Kossel open source 3D printer. The parameters used to produce the samples are layer thickness, fill density and speed of printing. Fourteen samples are prepared for every types of printing method which is for printing the samples with normal Kossel 3D printer and printing the samples with applied pressure (roller) using Kossel 3D printer as well. The standard of dog bone sample used to print is ASTM D638. Next, tensile test, surface roughness test and porosity test were made. It was found that, the quality and strength of the product can be improved after applying pressure on the printed part while printing process.

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji tentang sifat-sifat mekanikal acrylonitrile butadiene stryrene (ABS) yang digunakan secara meluas dalam bidang pencetakan 3D. Teknik yang digunakan dalam kajian ini adalah model pemendapan terlakur (FDM). Ia diketahui secara meluas produk yang dibuat oleh pencetak 3D sumber terbuka menghadapi beberapa masalah yang berkaitan dengan kekuatan produk. Pencetak 3D Kossel yang sedia ada boleh diubahsuai untuk menghasilkan kualiti produk yang baik . Berdasarkan jurnal-jurnal dan artikel-artikel yang ditemui daripada penyelidik tertentu, didapati bahawa dengan mengenakan tekanan ke atas produk yang dicetak, ia boleh meningkatkan kualiti produk tersebut. Oleh itu, sifat-sifat mekanikal ABS boleh dipertingkatkan selepas dikenakan tekanan ke atasnya semasa proses mencetak dijalankan. Penggolek direkabentuk dan dimasang pada bilah penyejuk pencetak. Rekabentuk penggolek dipilih melalui beberapa peringkat termasuk carta morfologi dan rekabentuk konseptual. Parameter yang digunakan untuk menghasilkan sampel adalah ketebalan lapisan, isi ketumpatan dan kelajuan pencetakan. Empat belas sampel disediakan untuk setiap jenis kaedah percetakan iaitu mencetak sampel normal dengan pencetak 3D Kossel dan mencetak sampel yang dikenakan tekanan (roller) dengan menggunakan pencetak 3D Kossel juga. Standard sampel tulang anjing yang digunakan untuk mencetak sampel adalah ASTM D638. Seterusnya, ujian tegangan, ujian kekasaran permukaan dan ujian keliangan dijalankan. Ia telah mendapati bahawa, kualiti dan kekuatan produk boleh boleh diperbaiki selepas mengenakan tekanan pada setiap lapisan sampel yang dicetak semasa proses pencetakan.

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Design
CATIA	Computer Aided Three-dimensional Interactice Application
FDM	Fused Deposition Modelling
PC	Personal Computer
RP	Rapid Prototyping
SLA	Strero Lithography
SLS	Selective Laser Sintering
STL	Stereo Lithography File
LOM	Laminated Object Manufacturing
USB	Universal Series Bus
UTeM	Universiti Teknikal Malaysia Melaka
3D	Three Dimensions

CHAPTER 1

INTRODUCTION

1.1 Project Background

Three-dimensional printing technology has been well known use and requires a large number of quantities in industry needed nowadays. Most of the regular or conceptual two-dimensional printer still remains the plane print, where the paper is printed with the text, graphics to be printed. However, since the technologies growth rapidly by times, the invention of 3D printer become a popular technology requires in engineering fields and human needs. The technologies of 3D printer began to be applied to design, digital product mould, industrial design, paint, and other fields. Meanwhile, there is still requires an enhancement on 3D printer due to stability, accuracy, and balance.

Additive manufacturing or well know as three dimensional (3D) printing technologies have been growth widely in engineering field. Nowadays, this technology has a various methods and types in order to print 3D parts or object layer by layer completely. stereolithography (SLA) is the one of the types of additive manufacturing which produces high-resolution parts. On the other hand, it is proved that SLA method in terms of producing 3D product is not long lasting. Hence, the other type of 3D printer is fused filament fabrication (FFF) or fused deposition modelling (FDM) has been commonly used to build parts depositing successive filament beads of polymer. A similar technique is uses including continuous fiber reinforced materials together with a resin are deposited in a 'green state'. Then followed by the process where the parts is placed under vacuum condition and heated in order to remove entrapped air voids. The air voids may trap and presented in the deposited materials; thus, the part will fully cured through this process.

Due to unstable and inaccuracy system development of 3D printer, a study of 3D printer properties as well as it mechanical characteristics, have been identified by certain researcher. Thus, this project is lead to enhance and identified the mechanical characteristic of components fabricated via low cost additive manufacturing.

1.2 Working Principle

3D printer built a part which support structure is create by fused deposition modelling (FDM) which is using thermoplastic blended material to form the model. The material containing a polyphenysulfone (PPSF) polymer and a polycarbonate (PC) polymer, which is good chemical resistance, thermal stability, and resist build-up through the nozzle of 3D modelling apparatus. The support structure is removed from a completed model while the material is hot to ease the process of removing. The depositing layers of solidifiable modelling material is extrude through the nozzle head and pointing to the printing table to form a layer of part. The molten extruded material is deposited layer-by-layer from nozzle head to the base. This technique use Thermoplastics as a material that suitable for deposition modelling process.

1.3 Problem Statement

Unstable and inaccuracy of 3D printer will cause problems on outcomes or the products. There are certain mechanical characteristics need to be improvised due to this problem that can cause a defect on parts of product. Meanwhile, to develop a low cost additive manufacturing system, need to be more precise on mechanical characteristics as well as it quality itself. Regarding to the low cost additive manufacturing, it may affect the quality of the object. Thus the strength, bonding, and complexity of the process also influence in order to produce a good part of 3D model. The existence 3D printer produces a model with a porosity structure and the structure need to be improved in order to enhance the strengthen of the 'dog bone' model. Thus, a few inventions and brainstorming an ideas process should be taken in this project.

1.4 Objective

In order to improvise and enhancement of 3D printing development, there are a few objectives related to this project. This project consists of skills to generate an idea to improvise the system of 3D printer in terms of low cost additive manufacturing. However, the objectives of this project are listed as below. The objective of this project is:

a) to study the mechanical properties of material used to produce the product made by 3D printer itself. It also included the tensile stress, tensile strain, maximum load and modulus of the material.

b) to design a suitable roller to improvise the mechanical structure of the sample.

c) to enhance the strength of the model on porous structure through various processes while the experiment is carried out. Thus the mechanical properties of the material used, ABS also improved.

1.5 Scope

The scope of this research including:

a) to improve the mechanical properties as well as the quality of the samples.

b) to produce a normal samples and samples with applied pressure made by Kossel 3D printer.

c) the experiment will be conducted for both types of samples for tensile test, surface roughness test, and also porosity test.

1.6 General Methodology

The actions that required in order to achieve the objectives in this project are listed below.

1. Literature review

   Commonly review on articles, journals, or any materials which related to the project.

2. Inspection

   The structure of the 'dog bone' model will be inspected and a few tests including tensile test will be run to investigate and examine the porosity against the 'dog bone' model.

3. Measurement

   The measurement will be based on the 'dog bone' model size. Meanwhile the actual product of 3D printer will be tested after the test is run onto the 'dog bone' model. The criteria of the strength and porous structure of the 'dog bone' model should be considered.

4. Simulation

   Simulation of the 'dog bone' model will be visualized and simulated through various software including CATIA, G-Code simulator and others to convert the file into '.STL' file form to proceed the process into the making of the model.

5. Report writing

   A report on this study is written during the project is carried out.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Additive manufacturing or commonly known as three dimensional printing where the process happened from designing the product from digital file to the real prototype or solid object. The process involve in the making of 3D printed object by using additive processes which specifically the successive layers are laying down and gradually made until the object is created. In order to print a 3D object, the manufacturer uses 3D computer-aided design (CAD) software to create a digital model. As a time grow rapidly in a term of technology, 3D printing methods become more accessible either in small or mid-sized businesses as well as home users. The cost of 3D printing gradually decreases due to the growth of new technology of 3D printing in industries uses. 3D printers are able to produce and create a small components such as toys or small mechanical components. It also tested as prototypes for experiment and analysis purposes.

In 1985, Michael Feygen was the first developer of 3D printer and this invention create various names including rapid prototyping, stereolighography (SLA), fused filaments fabrication (FFF), and also additive manufacturing. The materials used in the making of the product are based on the requirement and needs and some of it are use liquid polymer or gel; others use resin where the cost of material is slightly higher. The object is created by layers and these layers produced a thin sliced horizontal cross-section from the base of an object until the object is done layered to the top.

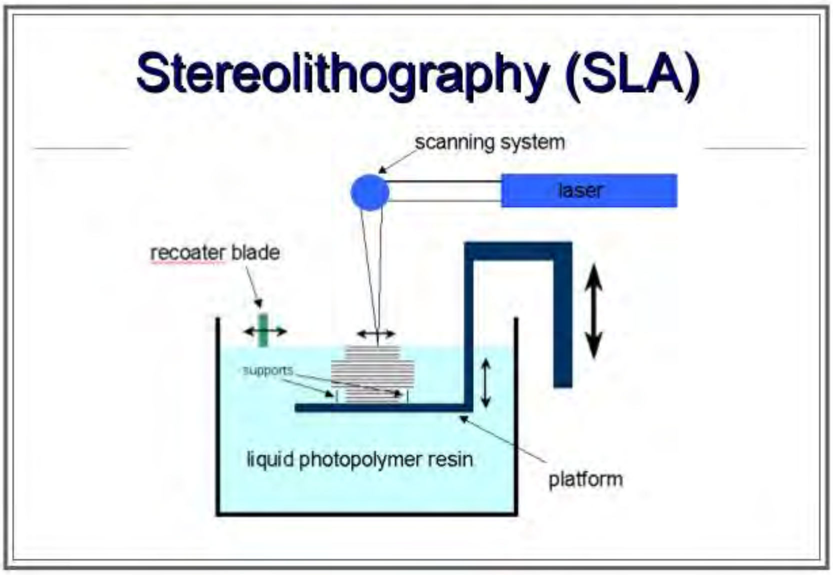


Figure 2.1: Stereolithography (SLA) diagram

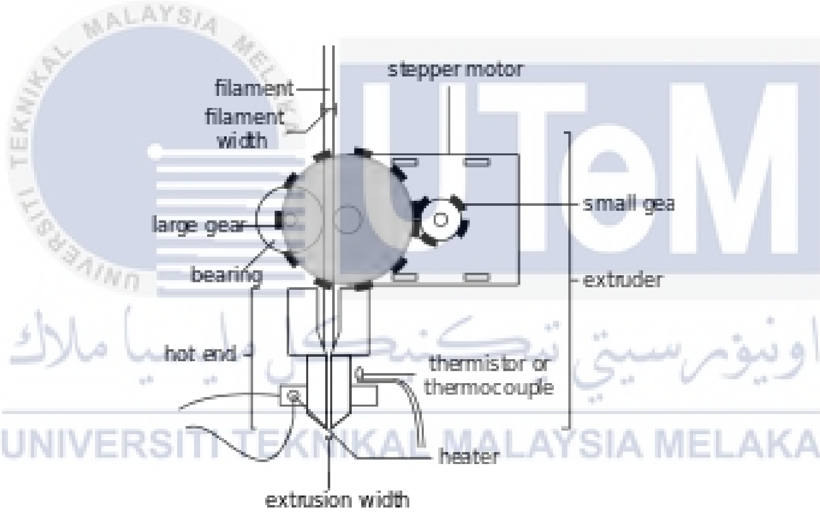


Figure 2.2: Fused filaments fabrication (FFF) diagram

2.2 Fused Deposition Modeling (FDM) Process

The 3D printer works when the virtual design is done by CAD programme to create an actual object through 3D printer. This software may develop a 3D modelling application. There is various ways to create a 3D modelling object. In industrial, the software used may cost thousands a year per license. But as a beginner or for a study purposes, it is advisable to subscribe free open source software, like Blender, for instance. When the 3D model is made, the next process is to prepare it in order to make it 3D printable. Certain technologies are involved in order to complete the process of 3D printing for instance a 3D scanner. 3D scanner can imitate an actual object in 3D digital copy.

Some of 3D printer not use the same technology and there are various way to print including additive, where the object are build layer by layer until the final object is complete. In order to produce the layers of an object, there are two methods either in melting of softening material to form the object. Generally, selective laser sintering (SLS) and fused deposition modelling (FDM) are commonly used in this technology of 3D printing.

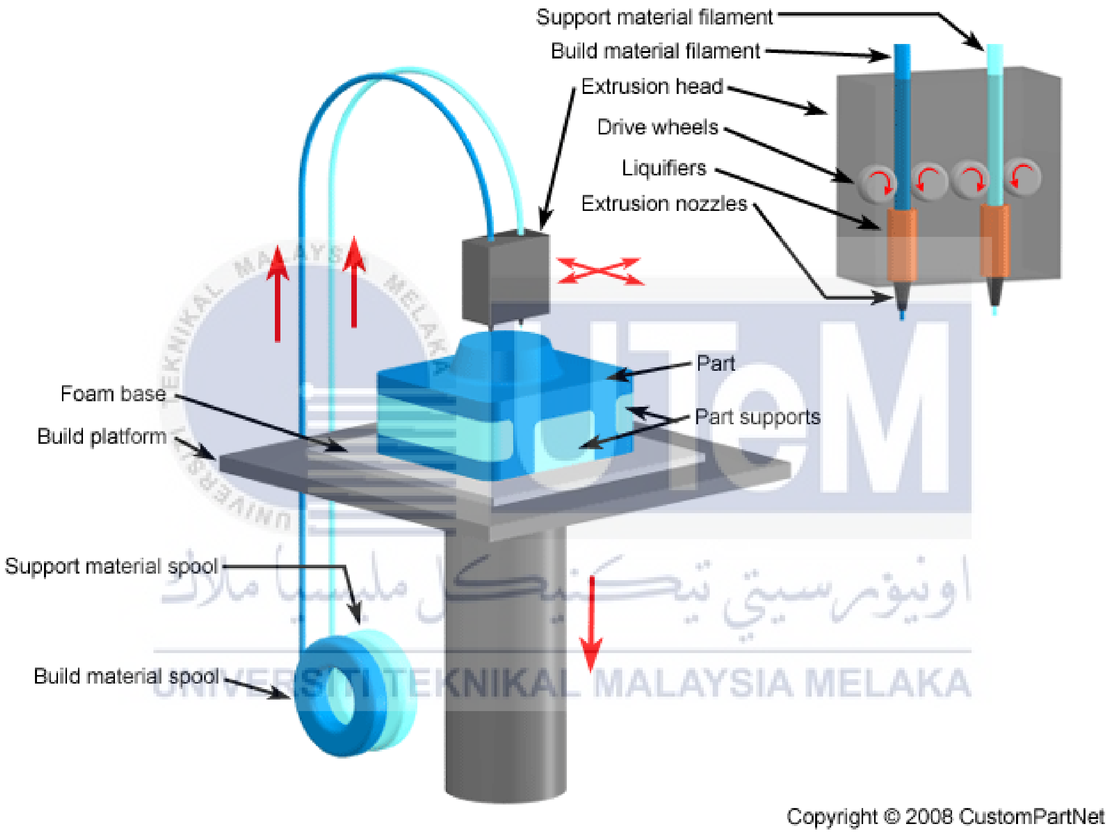


Figure 2.3: Fused Deposition Modelling (FDM) diagram

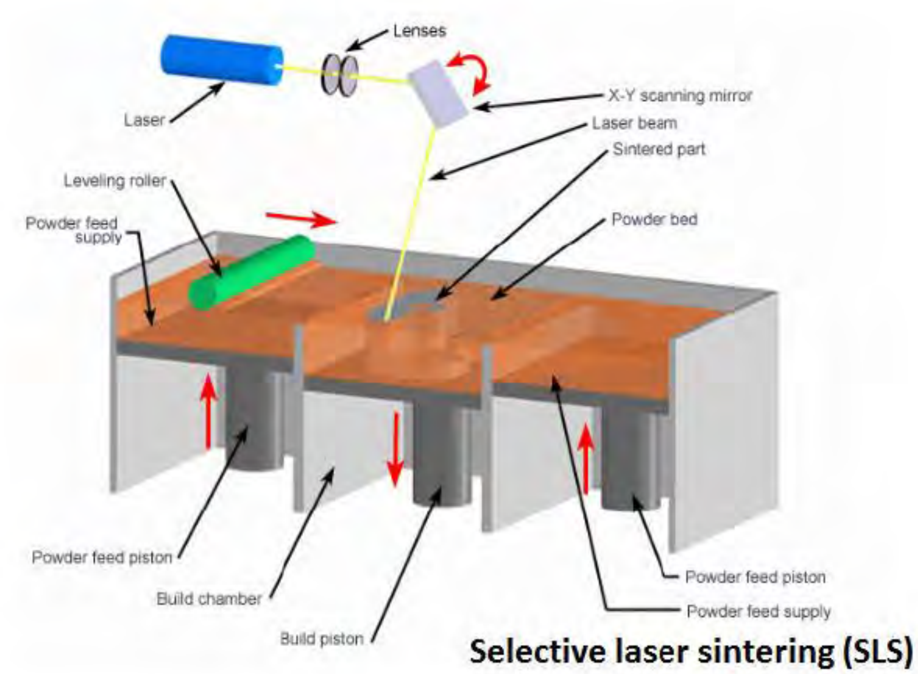


Figure 2.4: Selective Laser Sintering (SLS) diagram

2.3 The Advantages and Disadvantages of 3D Printing

The growth of 3D printing technology rise gradually since the product of 3D printer has been widely used for industry purposes, packaging, manufacturing and also for health care. Since this technique became popular, there must be a benefits and limitations of the 3D printing technologies towards human needs. So, here are just the main benefits of 3D printing. Basically, the traditional methods exposed an expert person to handle the tooling and machining works, while 3D printer has less tooling processes. Since the cost traditional way like injection moulding, are expensive, 3D printing is the best solution to replace the production cost as well as reduce the process of tooling and the labour cost to run the machine. Thus, the cost of production is much lower and affordable compare to the traditional ways. Then, the time management should be plan in certain project or task give. Thus, 3D printing requires a short and quick production without wasting time to waits until the product is done. In manufacturing industries, large quantities of production use the same mould and design to produce one shape at a time. Thus, the product only can produce the same shape and once the design change; the manufacturer should produce another mould. Meanwhile, a 3D printer itself may produce any shape and design base on desired design. In this way, people are freedom to customize the design base on the requirement. A 3D printer also produces better quality products. A 3D printing is so powerful that can create almost any shape, design from any materials such as metals, glass, paper and also even food. Moreover, 3D printing technology is better, cheaper, flexible, and faster.

However, this machine also has their own limitations and lacks due to production needs. The biggest issues related to the industries are the labour worker will having problems due to fewer workers in factory especially for the big companies. Manufacturing jobs will decrease with this new technology in industries. Recently, the usage of plastics, resins, certain metals and ceramics, is having a problem due to limited sources as a big consumer of 3D printer materials. Thus, the new development of studies for future materials of 3D printer material is still ongoing such as circuit boards. Since 3d printer becoming more common, the copyrighted product will become easier to duplicate and it is nearly impossible to detect the authentic of the product. Plus, it also can create dangerous items, even weapon such as knives, guns or any tiny parts. With the benefits of 3D printing technologies, people are easily to create the parts that have a same level with industrial does. However, the disadvantages of this technology need to be known to be understood and should be avoid for our future generation.

2.4 Acrylonitrile-Butadiene-Styrene (ABS)

Acrylonitrile-butadiene-styrene, ABS is known as thermoplastic resins with a combination of three kinds of monomers which consisting of acrylonitrile, butadiene, and styrene. Meanwhile, the group of these combinations make ABS as a good combination of hardness and softness by enhance its brittleness properties. Thus, by adding up the rubber components into these materials, it may enhance the hardness and fluidity of the polystyrenes. In addition, ABS also well known as a good type of excellent desirable properties, including fatigue resistance, chemical resistance, hardness, easy to handle, and also good mechanical properties. Therefore, it is not surprising if ABS products are widely used and also can be found in daily life. Nowadays, the number of ABS usage has gradually increased especially in rapid prototyping technology.

Figure 2.5: ABS filaments

2.5 Slic3r Software

Slic3r is the main software to be used to generate G-Code for 3D printer. At the beginning, from developing a 3D model in STL file format until it is exported to G-Code as a printing instruction to form a 3D sample. The software cuts the model into horizontal slices (layers), generate tool paths to fill them and determine the amount of material to be extruded. The general setting such as filament setting, printer setting, and also print setting can be set manually.

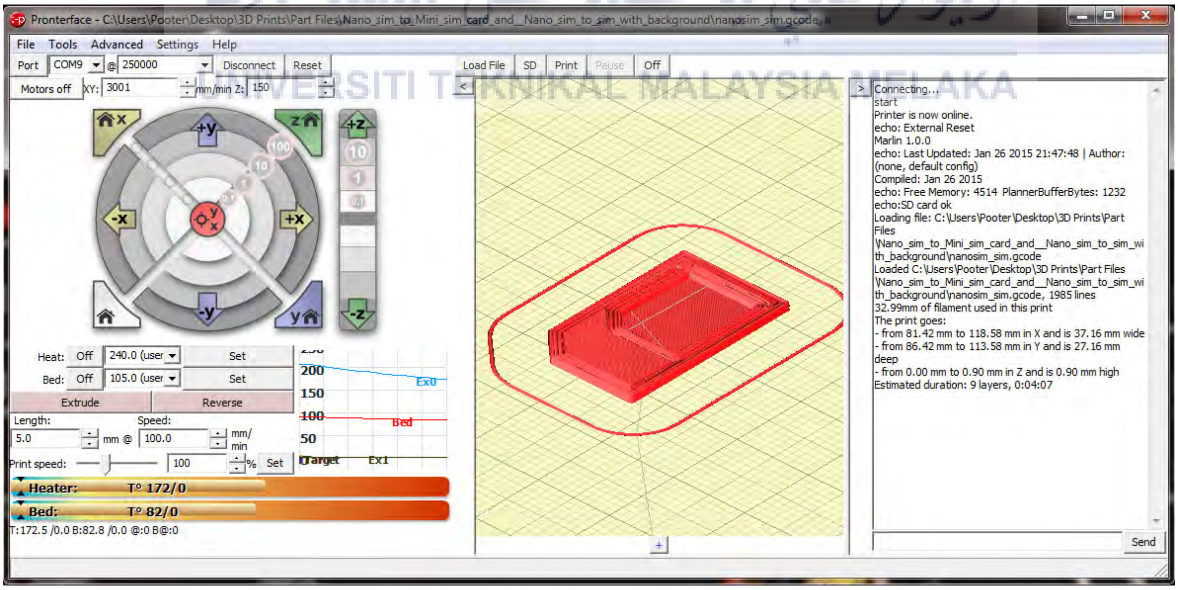


Figure 2.6 Slic3r Software's interface

2.6 Repetier Software

The Repetier-Host V1.0.6 software is a simple to use host software. Comparing with others slicing software around, this software is compatible with other firmwares. The STL file can be added directly on the simulated printbed on the software and it can slice as well into G-code file. In addition, there is built-in Slic3r slicer for slicing process. Just call "Slice & Load" and the job gets delegated to the current slicer, showing its output in the log window. In the G-Code editor, the current G-code file can be edited or it can be analysed. The slice process can be faster by using this software. Plus, after slicing process, the estimated time, number of layers and other information will be shows as user’s reference.

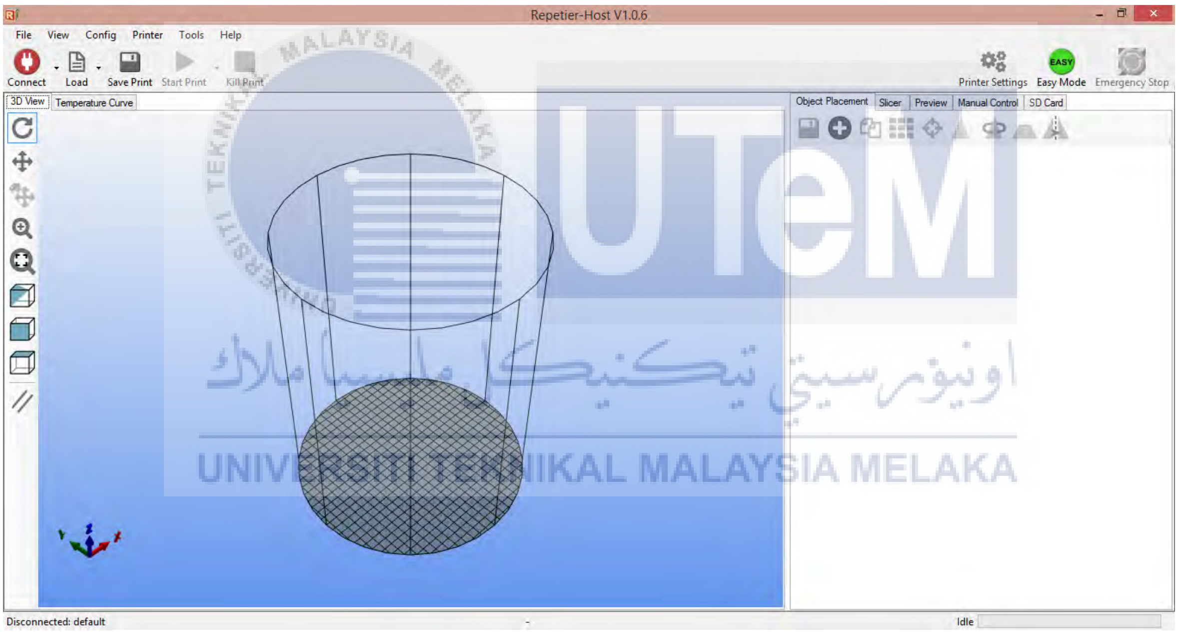


Figure 2.7: Repetier-Host V1.0.6 software‘s interface

2.7 CubePro 3d Printer

The CubePro 3D printer is a professional grade printer that office-friendly where it can be use at office or even at home. Plastic Jet Printing (PJP) is the consumer of the printer which certified for professional and home use. The machine comes with two types which is CubePro and CubePro Duo. The different between these two types is CubePro use only one filament while CubePro Duo can use two filaments with different material.

There are various features of CubePro 3D printer that can be discover by your own including stabilized printing environment and it is safe for home used. It also produced high accuracy product and the setting also automated. Thus, the machines need less effort to conduct the process of printing. In addition, the cartridge can be easily feed on the printer. This printer also is able to print different materials and colours including plastic (ABS, PLA) and nylon. The printer also built-in with Wi-Fi connections that ease the user to send the STL file directly to the printer.

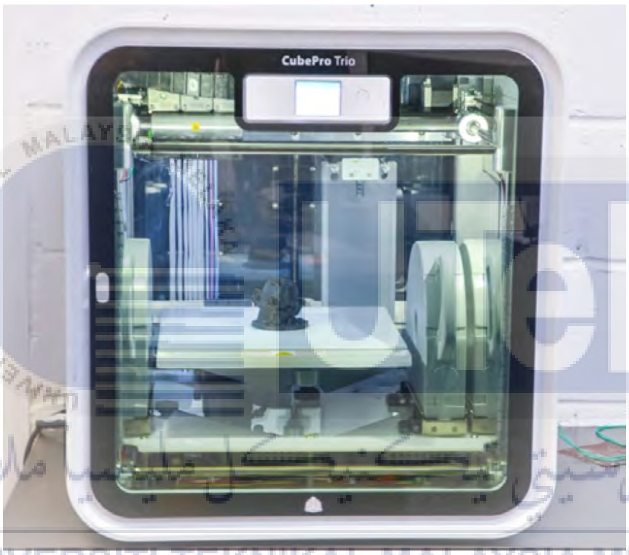


Figure 2.8: CubePro 3D printer

2.8 Tensile Test

Tensile test also known as tension test where the specimen is pull in an opposite direction. It is a fundamental of material science test where the specimen is subjected to a controlled tension until failure. The test is conduct to define the specific value of reaction from the specimen. The strength of the material depends on the material used. The general properties by using this test can be obtained such as ultimate tensile strength, maximum elongation and reduction in area. Related to the properties obtained, these following properties also can be determines such as young modulus, Poisson's ratio, yield strength and strain hardening characteristics

Figure 2.9: Instron Floor Mounted machine for tensile test

2.9 Surface Roughness

Surface roughness is the main role to determining a good product at finishing. A smooth surface of 3D parts is important, in the making of 3D printing product. In addition, a good surface texture can be tested through several tests. The largest value of surface roughness indicates the surface of the part is rough. While, if the value of surface roughness is small, the surface is smooth.

In real life, surface roughness gives a great impact towards our surrounding where an object may interact with its environment without realizing. A higher friction occurs when there is a wear happens quickly and it may affect the surface roughness as well. In addition, related to the mechanical properties of materials, roughness is a good predictor as it may reflect a sign of corrosion or crack before it is fracture. Meanwhile in production fields, a high roughness often occurred and it is difficult to control in manufacturing process. Thus, to reduce the roughness of the product may increase the cost of manufacturing.

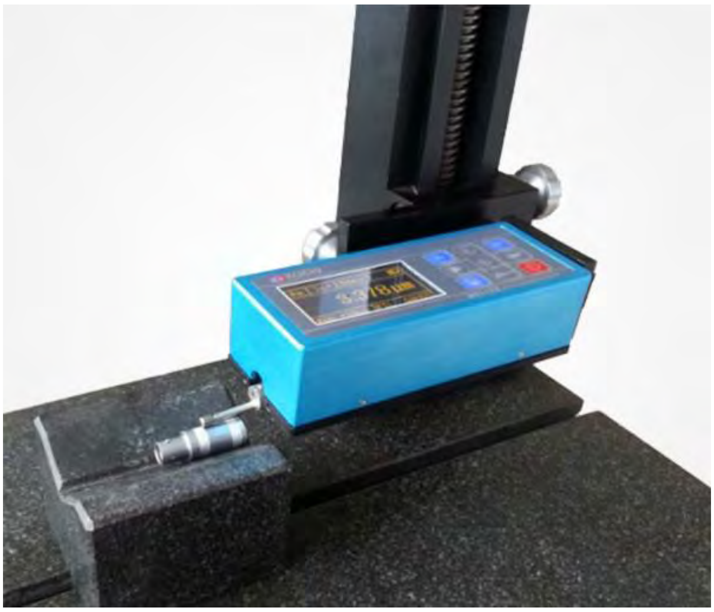


Figure 2.10 Portable Surface Roughness Tester KR210

2.10 Porosity Test

Porosity is the amount or quality of a material of being porous. It is a small cavity or a tiny hole inside solid material. Liquid or gas (air) may flow and go through these tiny holes if there is any porosity space. This kind of test can be conducted by two methods by using Image J software and the other one is by implementing a principle of Archimedes.

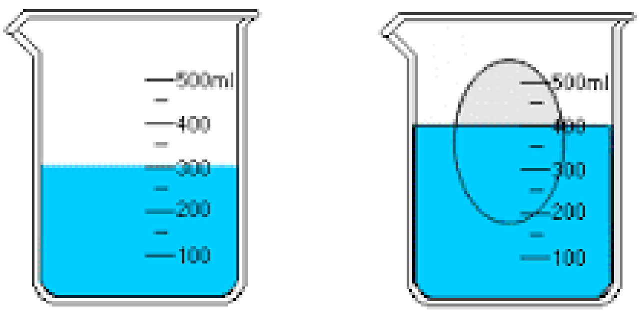


Figure 2.11 Archimedes Principle

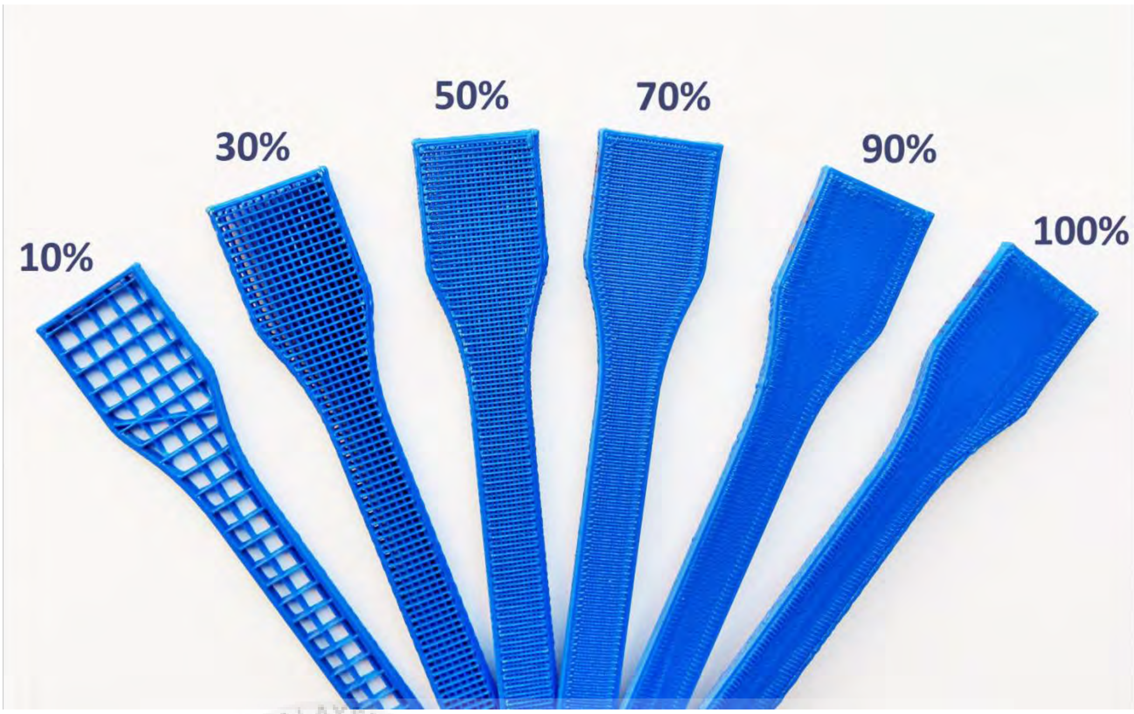


Figure 2.12 Percentage of fill density related to the porosity of 'dog-bone' sample

2.11 Experimental Setup and Preparation

According to the preparation of standard requirement for this experiment, there are various steps and procedures should be implemented to gain the best result for strength, porosity, and roughness of the sample. As example tensile test, surface roughness as well as porosity test which are include to determine the properties of the sample. It is advisable to refer to the material specification before conducting any test. For instance, according to this experiment, ASTM D638 is the most common plastic strength specifications and covers the tensile properties of unreinforced and reinforced plastics. The standard 'dog-bone' or 'dumbbell' shaped specimen used is ASTM D638 creates using 3D CAD software and thus it is exported in stereo-lithography (STL) format. In order to proceed this step, a QuickSlice program is needed to import the STL file format into the system. This program is provided by Stratasys to slice the part and send related commands directly to the rapid prototyping machine.

A universal testing machine usually for tensile testing machine is required to conduct this experiment. A proper preparation and better understanding for sample specification must be taken before conducting any tensile test from ASTM. This is just a simple procedures to clarify the steps should be taken to perform this test. Next step is to test the specimen using portable roughness tester for surface roughness test. The value shows the roughness of the specimen either high or low, where high value means it is rough while the small value shows the surface is smooth. Then, it is followed by the porosity tests which are divided into two methods. The specimen is tested using inverted microscope and also using principle of Archimedes to determine the density of the sample.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to complete this project, there are several steps and methodology should be implemented in this chapter, including experimental setup for tensile test, porosity test and surface roughness test as well. In this chapter, all the details about the preparation is briefly explain based on the design specification related to literature review of this project in Chapter 2. Before proceed to the next process, there are two types method use to produce the specimens (dog-bone shaped) before conducting the test. The sample produced by using normal open source 3D Printer and also the sample with applied pressure.

3.2 Flow Chart

A formal graphics of process flow is needed due to plan a good sequence while conducting an experiment in this project. It is a logic sequence or manufacturing process that provides people as a reference and guideline when dealing with any project or process. At the beginning, collect data and gain knowledge about the project or process as much as you can until the last part is completing the report followed by the sequence of the process. In this chapter, the processes, methods and techniques that used in this project are briefly explained in order to achieve the objectives.

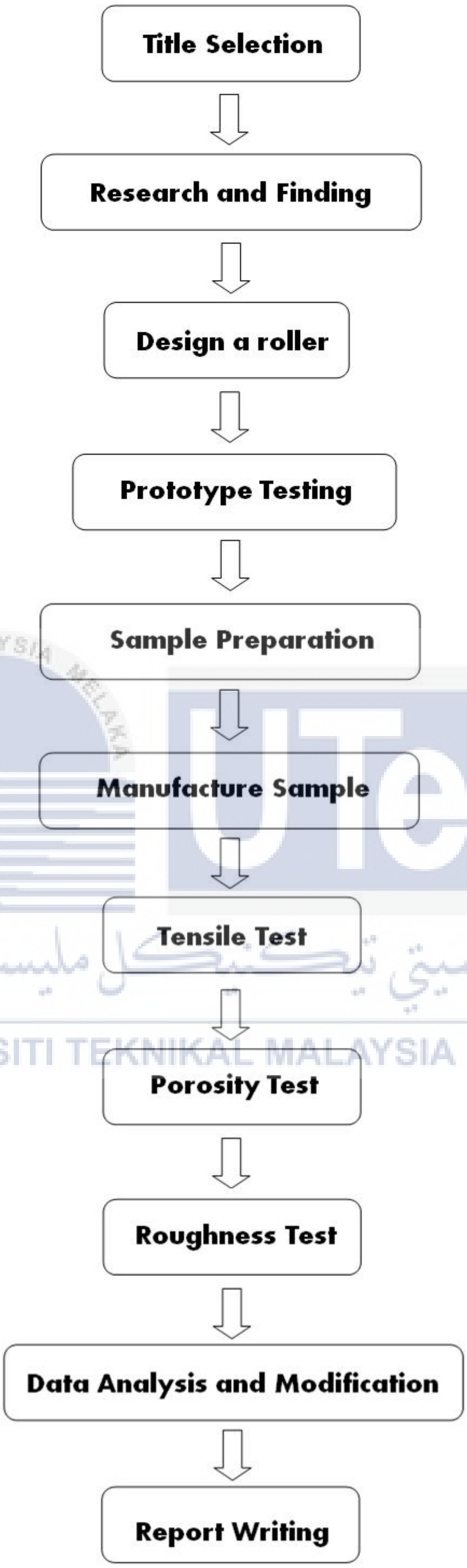


Figure 3.1: Flow chart

3.3 Sample Preparation

A dog-bone shape is modelled by using CATIA V5 known as CAD software and then saves as Stereo-lithography (STL) format file. Then, the STL file is imported into FDM software which is known as SLIC3R to slice the part. The STL file is converted into G-Code as it add into SLIC3R Software. The standard specification used in the making of the specimen is ASTM D638 as stated in Chapter 2 previously. Meanwhile, the material used to produce the sample is ABS. As mention before, the experiment required two types of methods which are by preparing the normal samples and sample with pressing. All of these methods will be discuss more on details for the next discussion. The specimens are ready to be tested after all the specimens are produced.

3.4 Set Parameter

After gather the information about the past investigation of effect of parameter in 3D printed material, brainstorming the idea of suitable parameters for the project is conducted. The fixed parameter and vary parameter is set. The fixed parameter for the sample is first layer height, fill pattern, speed for the first layer and the last layer, heated bead temperature and the filament. The vary parameter are layer thickness, fill density and printing speed.

3.5 Slic3r Software

Slic3r software is prepared based on 3D orientation such as X, Y and Z orientation. It is built based on the orientation as a guide. Slic3r is an o pen-source based which is comes with two modes, simple mode and the other one is expert mode. Generally, in simple mode, the option for modify parameter process is limited. Plus, it also not available for generating supports material in simple mode.

3.6 Repetier Software

Repetier-Host V1.0.6 software used to customize the printer setting and to slice the STL file into G-code file with estimated time to be printed on the open source 3D printer. The feature of setting can be customized as Kossel 3D printer parameter setting has variety parameter setting. In addition, in this software, the parameter used for the project is available including the layer thickness, fill density and printing speed as well.

3.6.1 Sample preparation

The STL file must be prepared first before it is load inside the software. Then, the printer setting and parameter can be custom as desired. The following figure shows the steps on how to load and open the STL file into the software. The software is ready to slice as the desired setting is done.

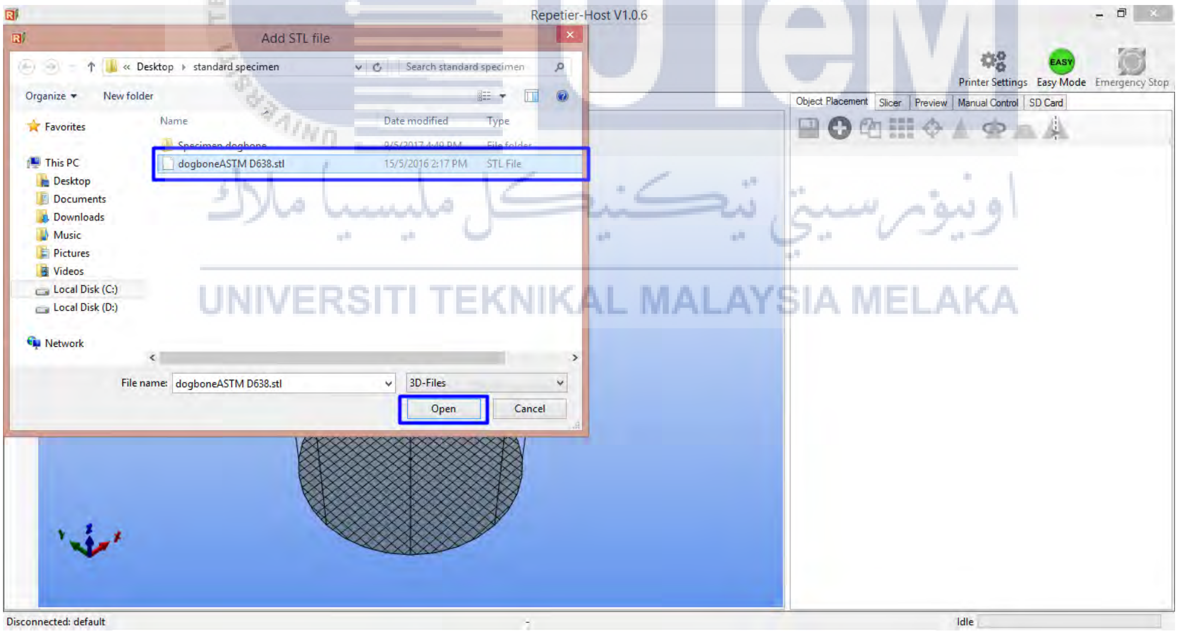


Figure 3.2: The STL File of ASTM D638 sample is load into the Repetier software

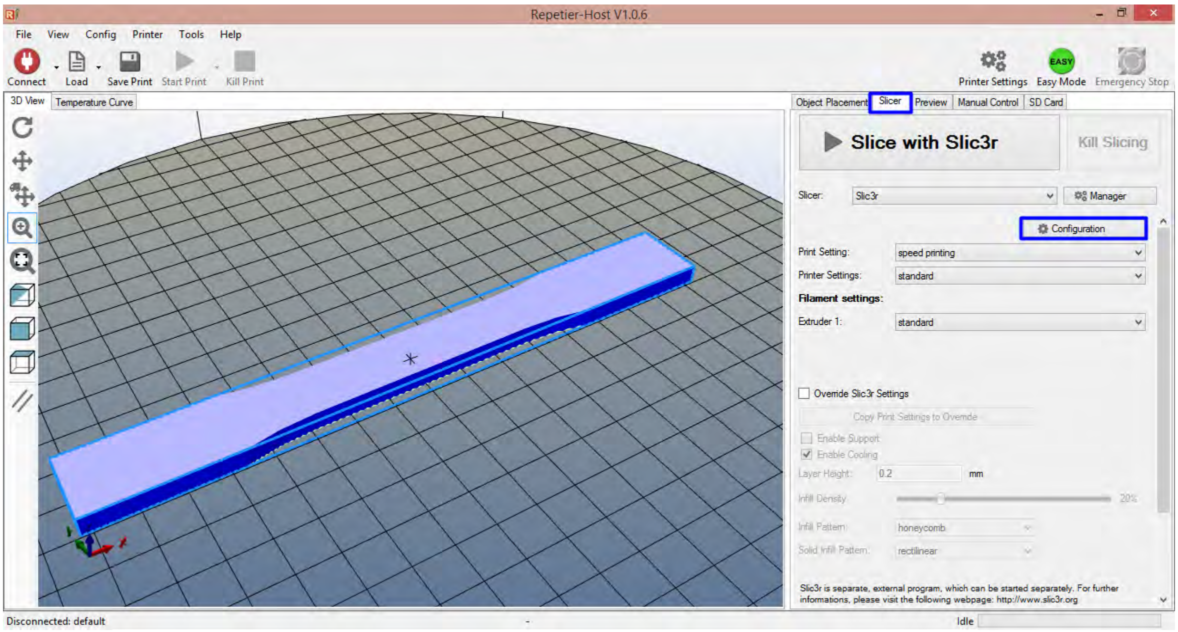


Figure 3.3: Printing setting in Repetier software

As the STL file is chosen, the 3D design drawing will appear and the part is ready to set up into certain parameter and printing setting.

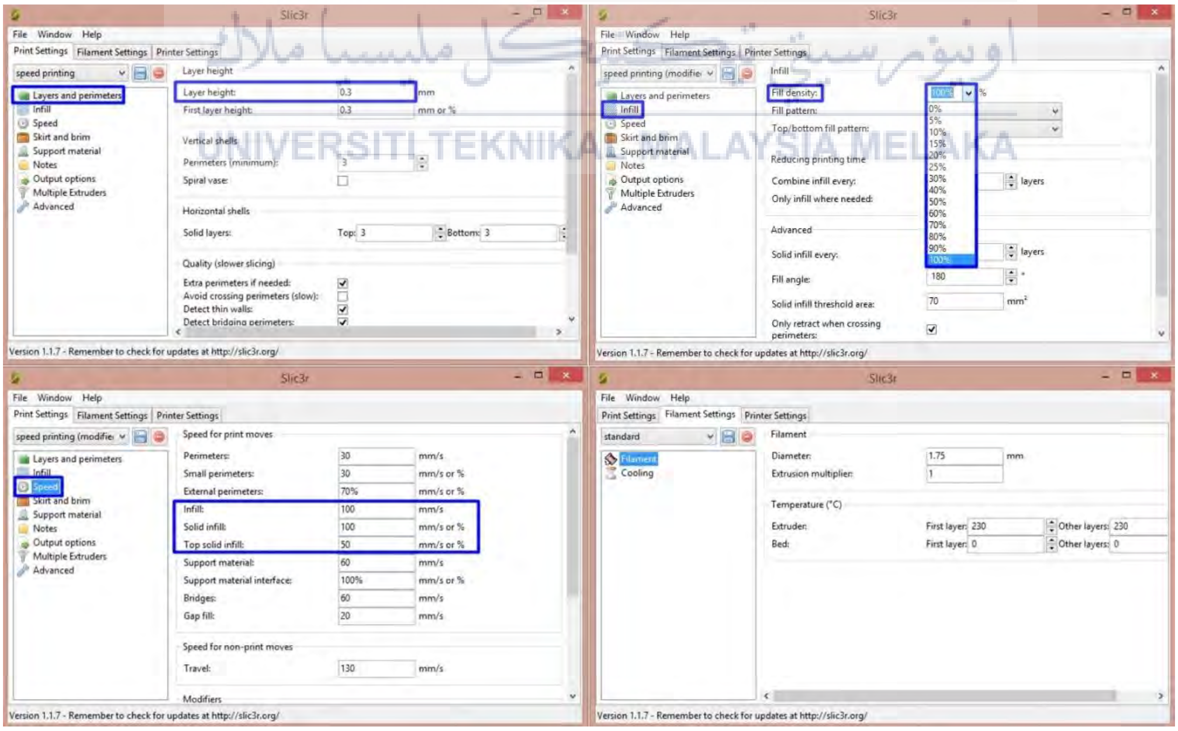


Figure 3.4: Printing set ups and parameters used for this project to produce sample

As the ‘configuration’ option is selected, the Slic3r set up is appeared. In this project, there are 3 parameters used to produced different sample. The parameters involved are layer thickness, fill density and printing speed. All the needed and desired setting can be done here.

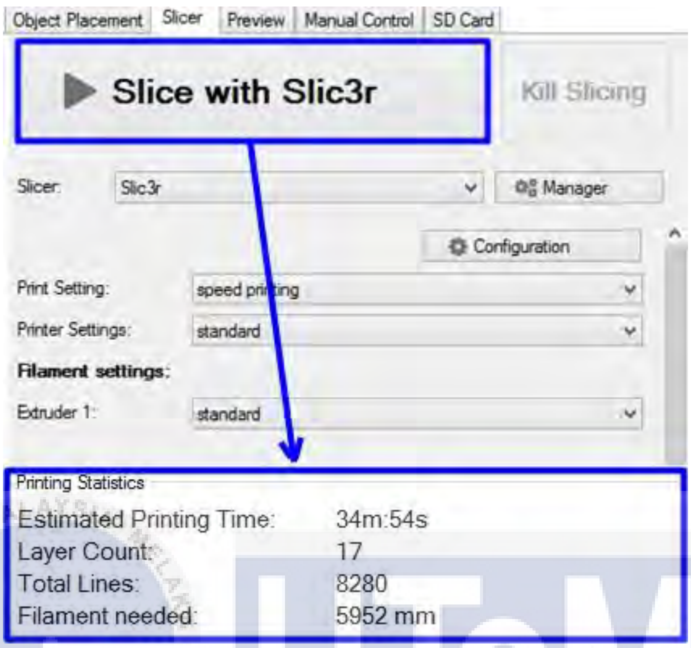


Figure 3.5: The estimated time and other important information for printing purpose

3.7 CubePro 3D Systems

Besides, for CubePro 3D printer itself, the software is built in and ready to use to import the STL file format. The software’s name also CubePro. Users are able to customize the type of material, colour, orient, scale, size and rotate the model by using this software. During build process, the software will slice it into layers and calculate the estimated duration for developing a 3D model. This process converts STL file to a CubePro to generate G-Code so that the printer can print a 3D model. Whenever the file format has been generated during build process, the file is unable to be edited although the original STL file can be used again to create another CubePro file type. The following interface shows a details options and buttons that can be used in this software

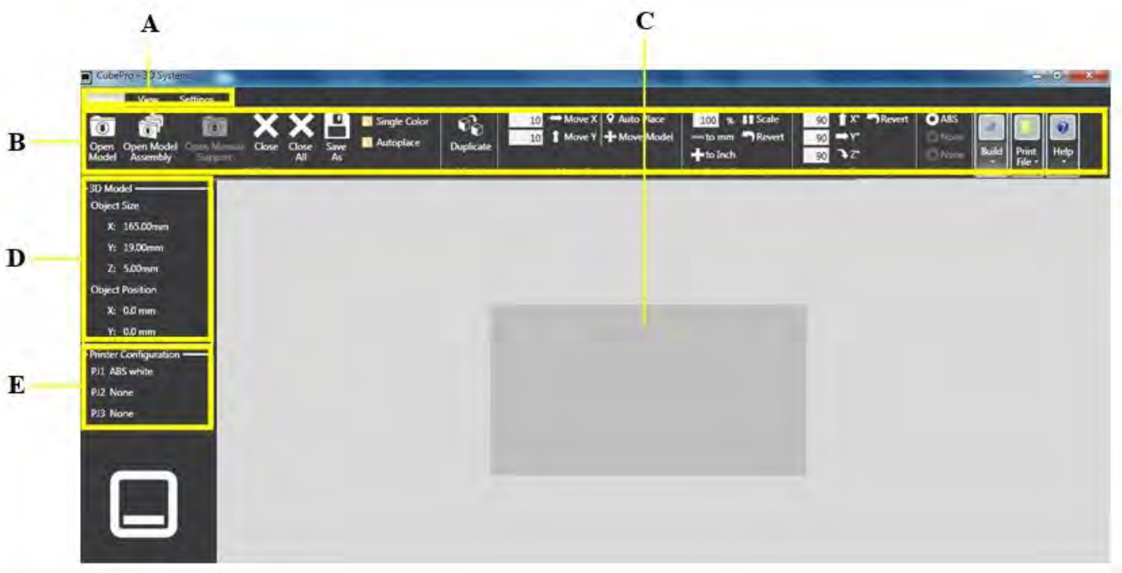


Figure 3.6: A CubePro 3D System's interface

Table 3.1: The description of main function of CubePro 3D System's interface

Letter	Description
A	Interface main tab.
B	Tool ribbon.
C	Stage.
D	Model size and position.
E	Print material configuration.

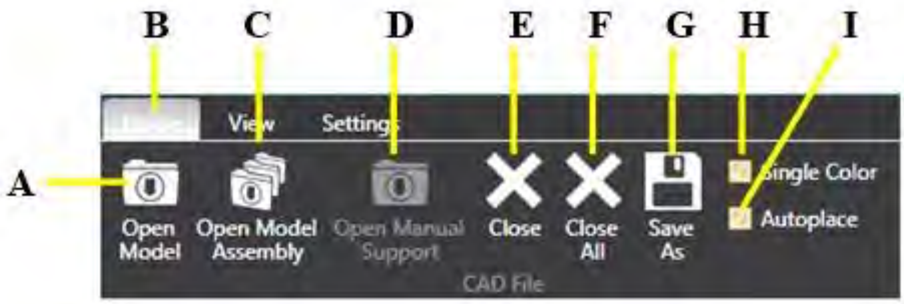


Figure 3.7: CAD files function

Table 3.2: The descriptions of CAD file function into STL file

Letter	Description	Letter	Description
A	Open a STL file.	F	Close all open STL file.
B	The main tab.	G	Save the current open STL file.
C	To open a multi-parts assembly of STL file.	H	Check the box if the model print using single colour.
D	Open manual support.	I	Relocate the model automatically.
E	Open and closed STL file.		

Figure 3.8: Geometry function for CubePro 3D System interface

Table 3.3: The description of geometric function for CubePro 3D System interface

Letter	Description	Letter	Description
A	Enter the appropriate values to move the model.	I	Scale the model by the specified percentage.
B	Model will move along horizontal axis as the value is added.	J	Undo the scaling and revert back.
C	Model will move along vertical axis as the value is added.	K	Rotating value to rotate the model.
D	Autoplace the model to centralized the print area.	L	The X axis by the specified value.
E	Select this button to drag the model into certain position.	M	Rotate the model left and right on the Y axis by the specified value.
F	Enter the scale percentage.	N	Rotate the model up and downon the Z axis by the specified value.

G	Scale the 3D model to the milimeter value entered in the field.	O	Undo the applied rotation and revert to the original position.
H	Scale the 3D model to the inch value entered in the field.		

3.7.1 Import a STL file format into CubePro 3D System

As the shape of the model is design using CATIA V5, the file format is save as STL file format. Then, the file is used to import into CubePro software to generate a G-Code for printing purposes.The following visual aids and figures shows a simple steps to print a 'dogbone' shape of ASTM D638.

As the software is open, select the 'Open Model' button at left top corner (located at Letter A, interface main tab) and browse the STL file that need to be print. Select the 'dogboneASTM D638' STL file, click 'Open'.

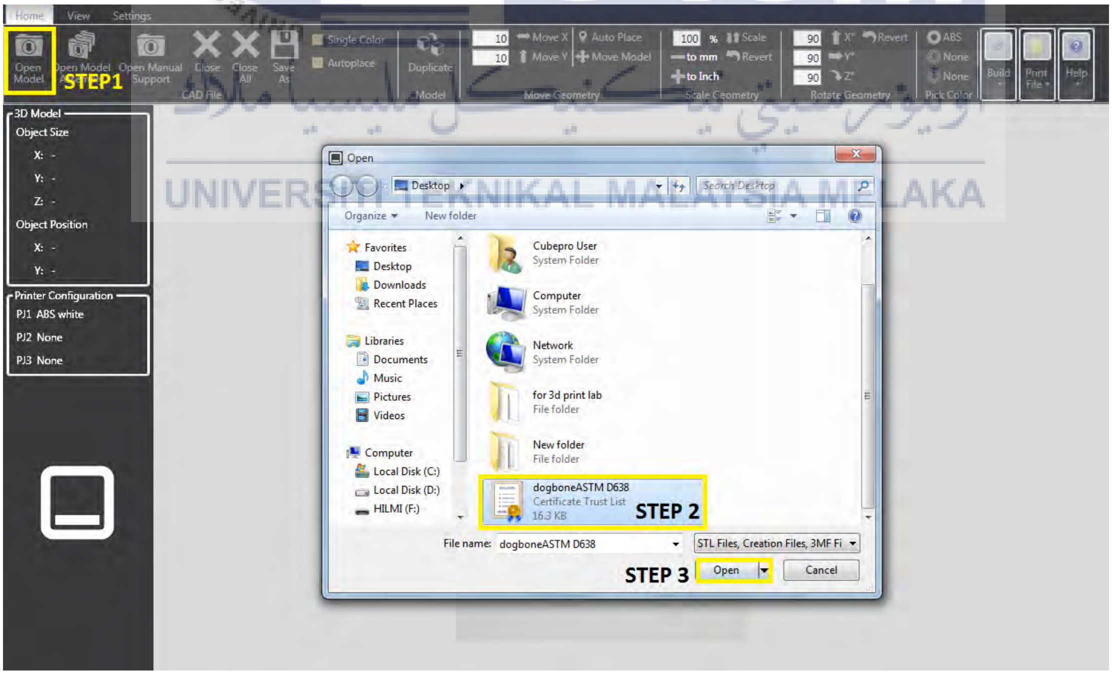


Figure 3.9: The interface of CubePro 3D system

The model of 3D is appeared on the stage area. Next, to customize the fill setting, click on the ‘Build Setting’ for details requirement of the printing model. Specifically, to test the ‘dog-bone’ shaped model, used the 200um layer resolution, select ‘almost solid’on print strenght option and lastly, choose ‘honey comb’ for print pattern. Meanwhile for ‘Advance’ setting, is for more option on fill setting requirement. The material used depends on the material install on the Filament catridge and for this test, the material used is ABS (white colour). Click on’Advance’ setting for more option of print pattern fill.

Figure 3.10: The ‘dog bone’ shaped is appeared

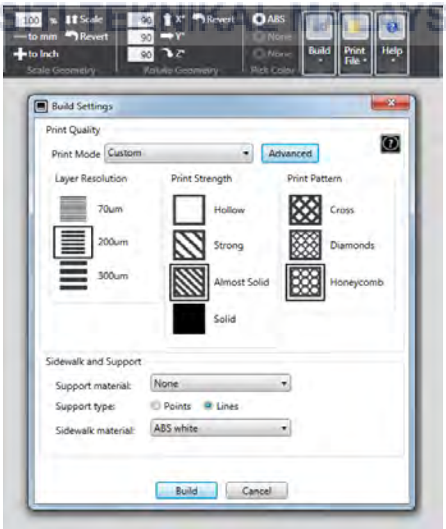


Figure 3.11: The Build setting interface

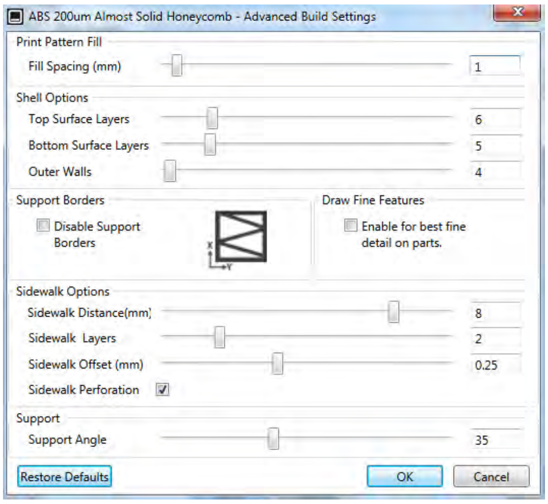


Figure 3.12: Advance build setting for fill measurement

Since this is the first specimen for CubePro printer, the fill spacing is 1mm and all other option still same. Click ok to proceed build the sample. Then, click 'Build' to finalized the option. Then, as this process is done, the software will calculate the mass of the model and as well as the estimated time to build the specimen. Next, user can send the file using Wi-fi connection directly to the CubePro printer. Make sure the Wi-Fi is connected each other to send the file to the printer. Lastly, the printer is about to start to print.

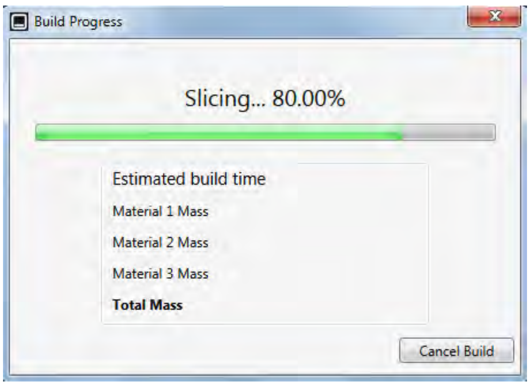


Figure 3.13: The software start to slice the model

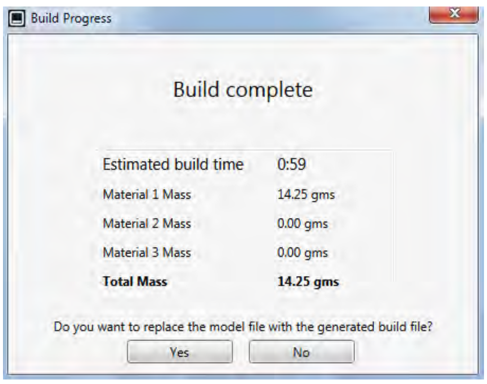
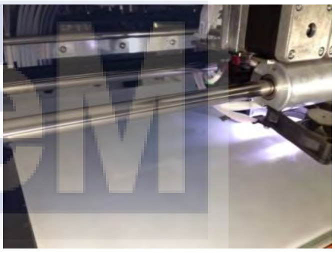
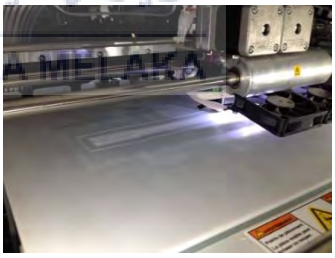
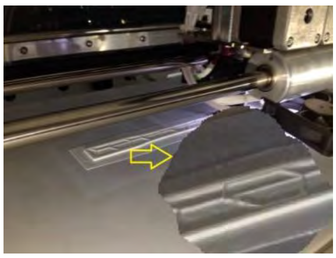


Figure 3.14: Build complete

3.7.2 Conduct a CubePro and ‘dogbone’ Process

The STL file format is export into a CubePro software and it is start to build through a few option shows previously. As the file is send to the printer, the printer will received a file from the computer or through USB (Universal Series Bus known as pen drive) device. The screen on the printer will appear the model to be printer as well as the progress of the model build. At the beginning, apply glue on the platform inside the CubePro printer and let the printer continue the printing process by itself.

Table 3.4: Steps on handling CubePro 3D Printer

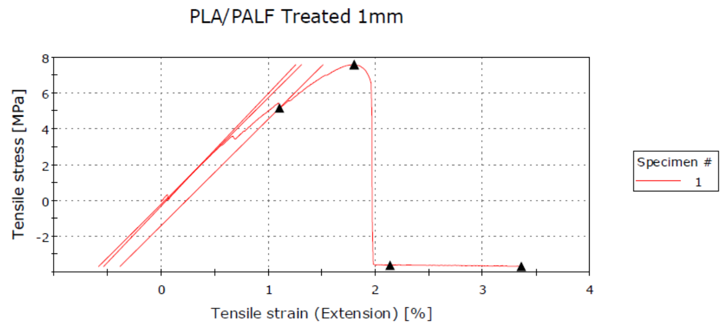
Step	Description	Figure / Visual aids
1	Apply glue on the platform of the printing area. Make sure the glue is cover all the space that need for model to be printed.	 Figure 3.15: Glue is apply
2	The chamber is heated up to melt the filament and the filament will extrude through the nozzle. The printer starts to print the first layer as well as the sidewalk.	 Figure 3.16: ‘Dog bone’ model at first layer with sidewalk
3	The printer starts to fill the center of the model with ‘honey comb’ print pattern.	 Figure 3.17: The ‘Dog bone’ model with ‘honey

		comb’ print pattern
4	The complete model of ‘dog-bone’ is produced. Use shizzle or any right tools to remove the 3D model form the printing platform. Handle it with care.	 Figure 3.18: Complete ‘ dog bone’ specimen printed by CubePro

3.8 Tensile Test

Tensile test was carried out by using Instron Floor Mounted machine as shown in Figure 3.20. The laboratory is located in Industry Campus, Faculty of Mechanical Engineering, UTeM at Material Structure Laboratory. It consists of 14 sample form normal 3D printer and another 14 samples were made with applied pressure (roller). Every specimen comes with different layer thickness, different fill density and different printing speed. The maximum tensile strength, stress, strain, and modulus of elasticity can be defined right after the specimen undergoes the failure process. Next, the result obtained is recorded.

The Instron machine is control and monitor by Instron Bluehill3 software. The Instron Bluehill3’s result is shown as Figure 3.20. As the specimen is install on the clamp, the balance strain and balance load are automatically reacted. Besides that, this software provides a flexible material testing package and also user friendly where it is suitable to use for learning purposes. Next, as the test is done, the value and graph plotted of tensile stress against tensile strain was generated by Instron Bluehill3 software.



	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [GPa]
1	567.63	7.57	0.02	0.57

	Load at Break (Standard) [N]
1	-272.42

Figure 3.19: Sample of result from Bluehill3 software

The value of tensile strength for every specimen was collected. Thus, from the result obtained, the value of young modulus was calculated using this software as well.

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Figure 3.20: Instron Floor Mounted machine

Figure 3.21: The facture specimens after tensile test

3.8.1 Steps to Conduct Instron Machine

1. The load is checked and six head screws are installed and tightened.
2. The frame is connected to the cell.
3. The Bluehill3 Software is opened.
4. The machine is calibrated.
5. The adapter is installed.
6. The parameters method is verified on Bluehill3 Software.
7. The load is programmatically balanced.
8. The dimension of specimen is inserted.
9. The specimen is installed.
10. The test is started.
11. The test is finished.
12. The result is obtained and the broken sample is removed.

3.9 Porosity Test

The tests of porosity were tested on 28 samples made by Kossel 3D printer. All the experimental setup and experiment were tested in Material Science Laboratory located at Industrial Campus, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, UTeM.

Every 28 specimens were tested and measured by using ImageJ Software. The image is captured by using ImageJ Software and it is free platform software used in image processing. There are several features contained in this software where the image is able to view, edit, analyze and also animate. Every specimen with different parameter is captured to produce a porosity image through the software. Thus, the result obtained may vary due to different parameter or pattern spacing for every tested specimen.

On the other hand, to measure the porosity of the material, the principle of Archimedes also can be used to determine the percentage of porosity. The equation that involved in this test is shown in equation 1 to define the density of the specimen. Next, it is followed by equation 2 to define the percentage of porosity of the specimen. The weight of the specimen is measured using digital weight balance before conducting this test. The specimen is submerged inside a graduated cylinder that fills with water. The volumes of water before and after submerging the specimen are recorded. Thus the data obtain form the calculations are tabulated for every specimen.

$$\textit{Sample Density} = \frac{Mass\ of\ Sample}{Volume\ \ of\ Sample} \qquad (1)$$

$$\textit{Percentage of Porosity} = \left[1 - \frac{Sample\ \ Density}{Material\ \ Density}\right] \text{x}\ (100) \qquad (2)$$

*Material's Density (ABS) = 1.04 $^{g}/_{cm^3}$

3.10 Surface Roughness

There are several specimens from normal samples and samples with pressure were being tested to determine the surface roughness of the specimen itself. 14 specimens of 'dog-bone' for each printer were prepared for the surface roughness test measure using a Portable Roughness Tester as shown in Figure 3.22. While conducting this test, make sure the path of taking the measurement is correct. By referring Figure 3.23, the arrow shows the pathway of surface roughness measurement. In order to gain a better result, every specimen undergoes a three-time measurement. The average value of every specimen will be recorded. The measurement of roughness was tabulated and bar graph of average roughness was analyzed.

Figure 3.22: Portable Roughness Tester

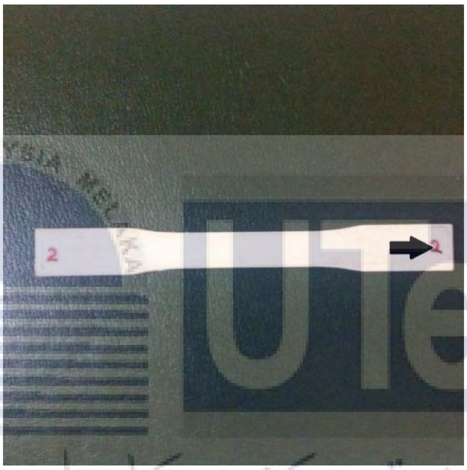


Figure 3.23: A specimen with pathway direction

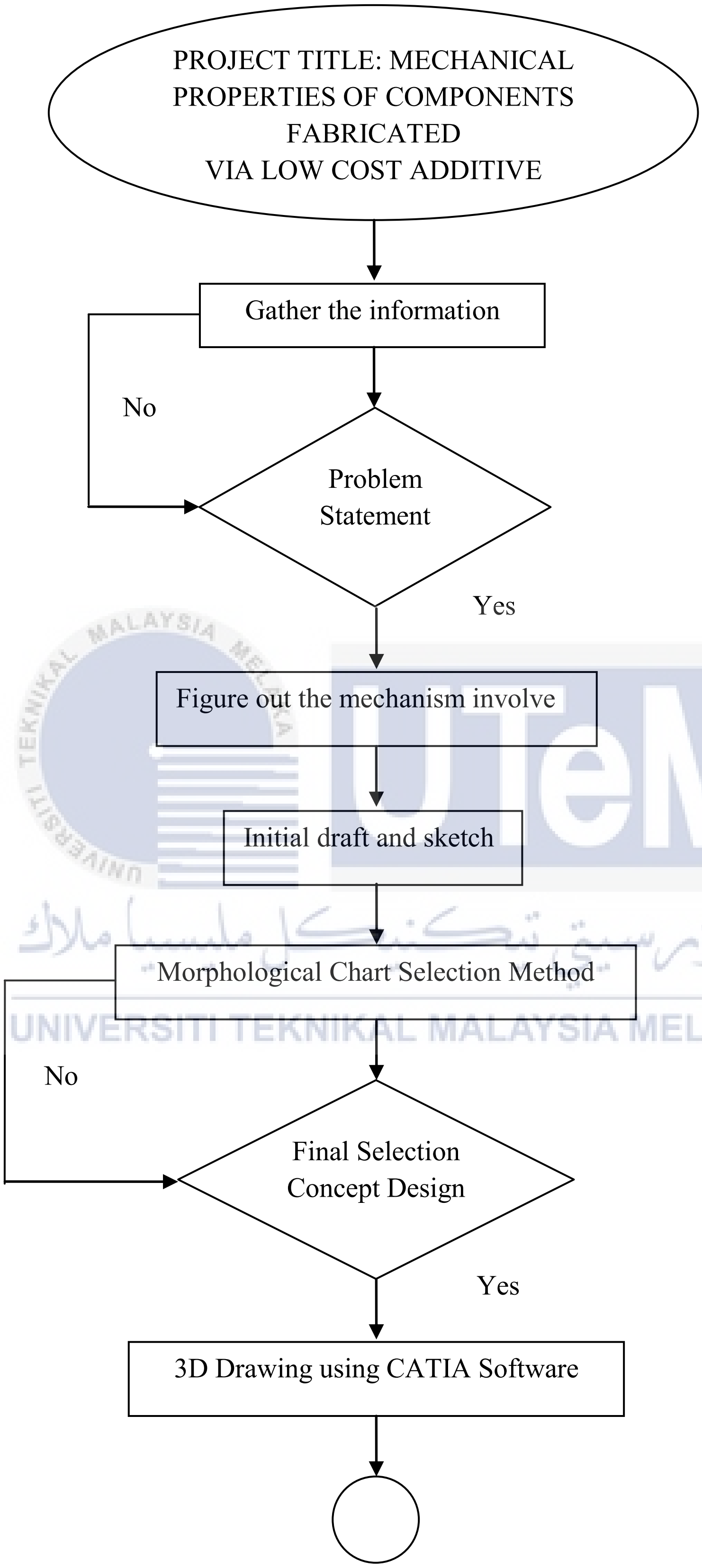
3.11 Roller Design

At the beginning of this chapter, the concept design of the prototype need to be select before proceed with printing a sample from open source 3D printer. The selection of the design have various steps and flow including project flow chart, morphological chart, conceptual design, CAD drawing, fabrication and installation and lastly prototype testing. Then, the samples of dog-bone are produced from an open source 3D printer with applied pressure. The samples were tested on tensile test, surface roughness test, and porosity test.

3.11.1 Project Flow Chart

A sequence of project flow start from project title until the prototype is done where the flow is representing in algorithm form. The flow is shown in a shape of boxes depends on the optional of the flow. The connecting arrow is use to show the working flow of the process. Basically, to make a modification of the printer, an earlier investigation need to done to ensure the dimension, movement axis of the nozzle and the size range of bedsize of the 3D printer. Next, the initial draft of the installed parts is made and the any mechanism involve in the project is figured out. The part of the components can be choosing separately based on the morphological chart and its optional design.

Thus, the assembly and fabrication process for the new improve part is made and ready to install to the 3D printer part. The functioning of the machine will be test as the prototype part is installed to the 3D printer. The comparison will be made from the between the normal printed part and applied pressure printed part using open source 3D printer. The flow cycle will be continue if there is any failure made on the printed part and the prototype have to modified for second attempts. Finally, as the experiment is succeed; the demonstration session will be take place for product presentation.


PROJECT TITLE: MECHANICAL PROPERTIES OF COMPONENTS FABRICATED VIA LOW COST ADDITIVE
Gather the information
No
Problem Statement
Yes
Figure out the mechanism involve
Initial draft and sketch
Morphological Chart Selection Method
No
Final Selection Concept Design
Yes
3D Drawing using CATIA Software

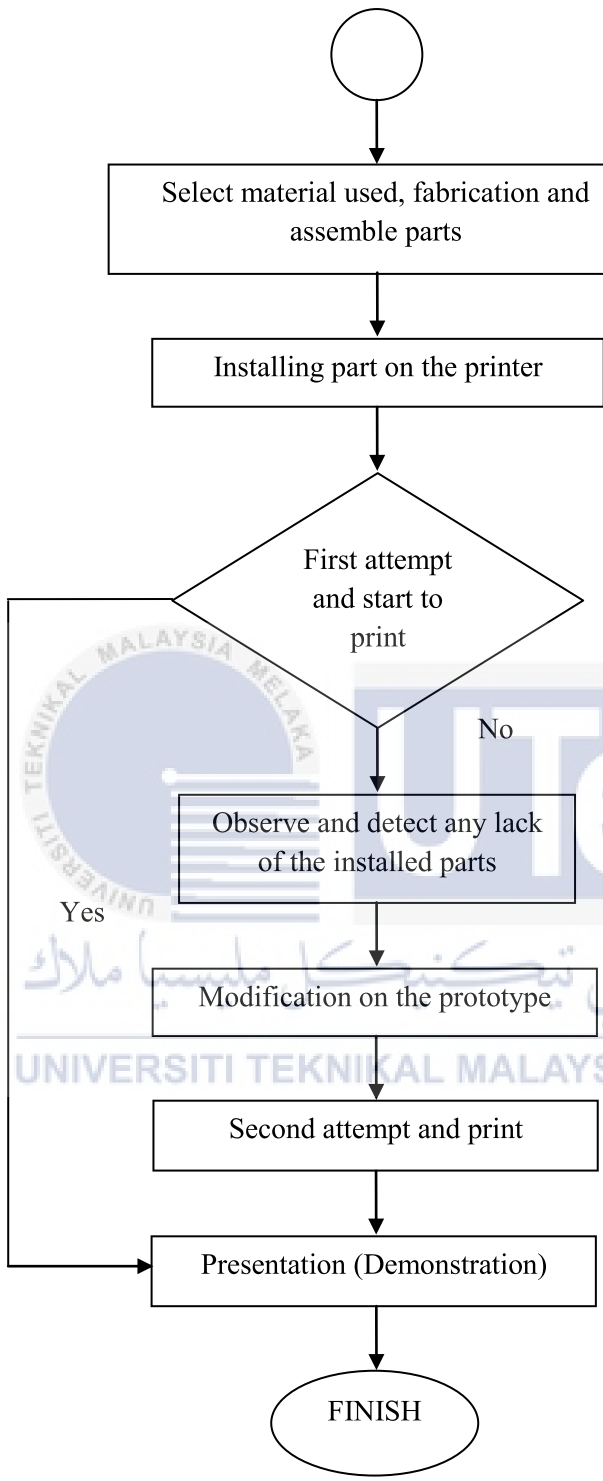
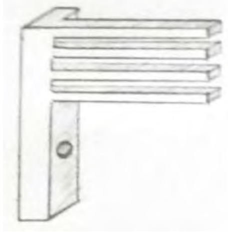
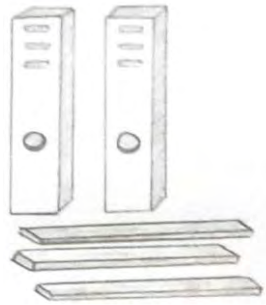
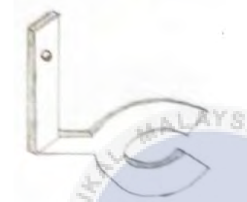
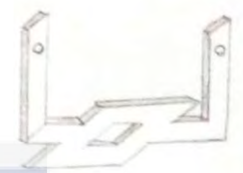
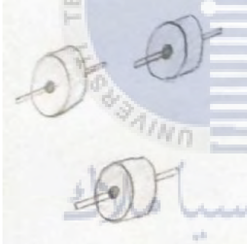
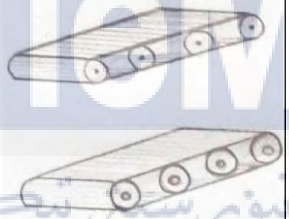


Figure 3.24: Project Flow Chart

3.11.2 Morphological Chart

Table 3.5: Morphological Chart

	Option 1	Option 2	Option 3	Option4
Arm (Holder)				
Base of Roller				
Roller				

3.11.3 Conceptual Design

Table 3.6: Concept Design 1

Part	Option
Arm (Holder)	1
Base of Roller	1
Roller	2

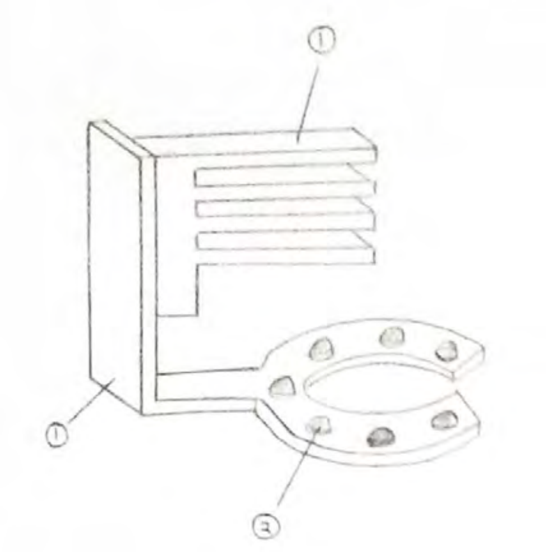


Figure 3.25: Concept Design 1

The selection of parts in Concept Design 1 is used a single arm (Option 1 – Arm). Thus the option of an arm must be match with any base of roller with single arm. So, the 'Option 1' is chosen as a base of roller with a design looks like a 'horseshoe' shape. The roller type chosen is 'Option 2' which is bearing type.

Table 3.7: Concept Design 2

Part	Option
Arm (Holder)	1
Base of Roller	2
Roller	1

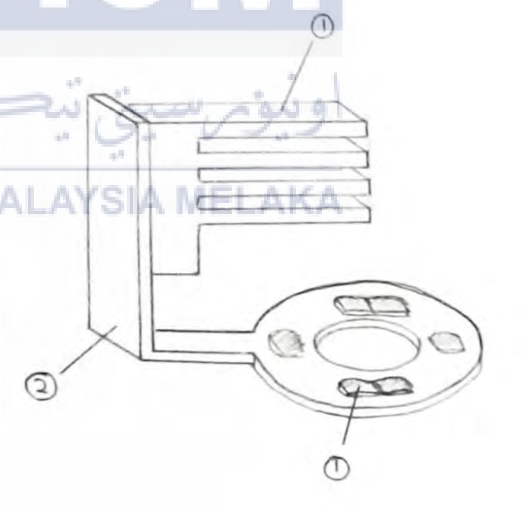


Figure 3.26: Concept Design 2

The base of the roller used is 'Option 2' where the base shape is circle type and the roller type is 'Option 1'. The roller is flat as a trolley tire where the surface is flat, but this type of tire are not suitable for 2-ways movement cause it will rolling only for one direction. Next, the arm used is 'Option 1' which is single arm type.

Table 3.8: Concept Design 3

Part	Option
Arm (Holder)	2
Base of Roller	3
Roller	2

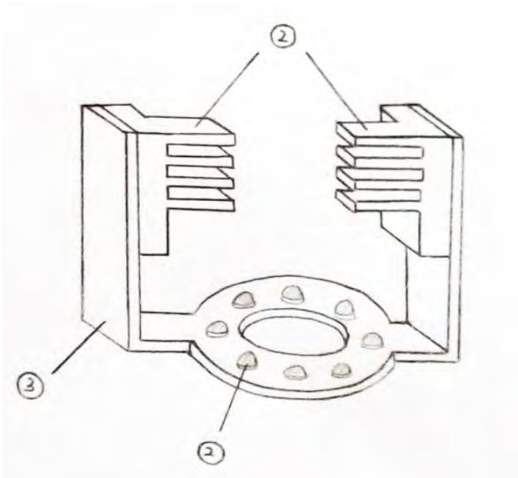


Figure 3.27: Concept Design 3

While for Concept Design 3, the usage of arm upgrade into double arm as well as the base of the roller have double arm holder, which are 'Option 2' and 'Option 3' respectively. This is due to stability of the holder. So, that it can hold the fan of the printer neatly. Then, roller used for this design is bearing type which is 'Option 2'. The base of the roller is circle shape

Table 3.9: Concept Design 4

Part	Option
Arm (Holder)	2
Base of Roller	3
Roller	2

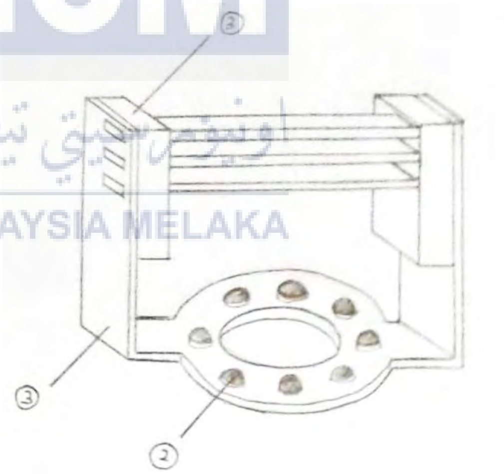


Figure 3.28: Concept Design 4

Next, for Concept Design 4, the base of the roller uses the same base and same roller type as Concept Design 3 which is 'Option 3' and 'Option 2' respectively. But, the arm used is different as shown in morphological chart, 'Option 3'. The arms in 'Option 3' have two parts which is the arm and the arm slots. It is much easier to install and easy to take off from the printer fan. The base of the roller is circle shape.

Table 3.10: Concept Design 5

Part	Option
Arm (Holder)	3
Base of Roller	4
Roller	3

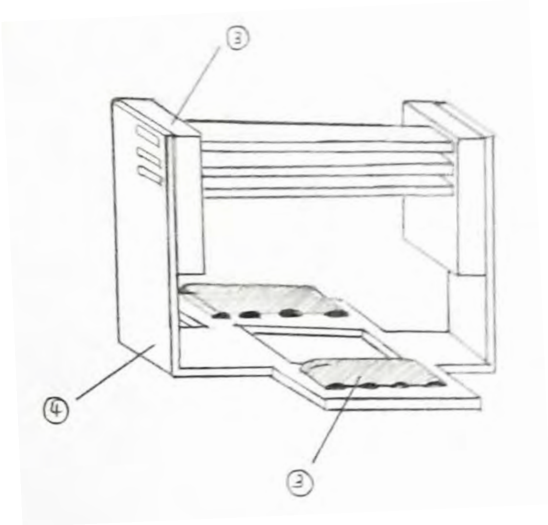


Figure 3.29: Concept Design 5

Last option for the concept design uses the base of the roller in 'Option 4', where the base is 'rectangle' shape. The roller used in this concept design is conveyor type (Option 3). The lack of the roller is only can roll one way direction but it may applied more pressure on the printed part surface. Then, the arm selection is 'Option 3' which is easy to assemble and take off from the fan printer.

3.11.4 Computer Aided Design Drawing

CAD drawing is important in order to design a visual 3D design by using CATIA software. In CAD, the precision and accuracy of the dimension is high. Thus, to produce a prototype using this software is very crucial to produce a 3D design. Based on the concept design selection, the selected design will proceed to the next step which is producing a 3D drawing using CATIA software.

3.11.5 Fabrication

Fabrication is the manufacturing process of raw or semi-finished materials besides of being assembled from ready-made component. In order to produce a prototype of roller, there are several component needed are in ready-made form such as bicycle bearing (can be a base of the roller) and 'L-Shaped' steel bracket (as an arm). Thus, it is much easier to fabricate the parts. The arm of the roller can be produce or 'custom' by using CubePro 3D printer and the 3D drawing must be design using CATIA software.

3D printer used to print the part of the prototype is CubePro 3D printer which is located in Prototype Laboratory, Kompleks Makmal Kejuruteraan Mekanikal (Fasa B). Next, to assemble the parts, some metal work can be done in Welding Workshop for grinding, drilling and welding works. This fabrication process also includes the assembly of the component.

3.11.6 Prototype Testing

Testing will be made after the actual design was completely fabricated and installed onto the nozzle part. These components were included the roller and the holder part that need to be assembled and merged together into one part. Prototype testing is important due to check whether the mechanism involved were fully working or else not fit on the part that need to be assembled. Moreover, from the first attempt of installation process, the part that used to attach on machine must be tested and followed by modification process if there was changes in design that need to be done.

3.11.7 The Actual Design

Based on the Concept Design selection, there were few characteristic had been chosen that found very suitable for the Kossel, 3D printer. The roller type used is 'bearing type' that eases the movement of pressure object on material for different axis and direction. Then, followed by type of holder used was available for both side holders to make it stable to hold the roller on nozzle fan. So, the ideal concept design chosen was Concept Design 3 and the material used and method to fabricate the roller were chosen. The roller used was metal bearing and combined with 'L' bracket. The process to combine the parts was MIG welding that had been done in Welding Workshop, Fasa B, FKM. Next,the holder was made by using Cube Pro 3D printer and the design was made by using CATIA V5 software. Below are the actual design that have been chosen.

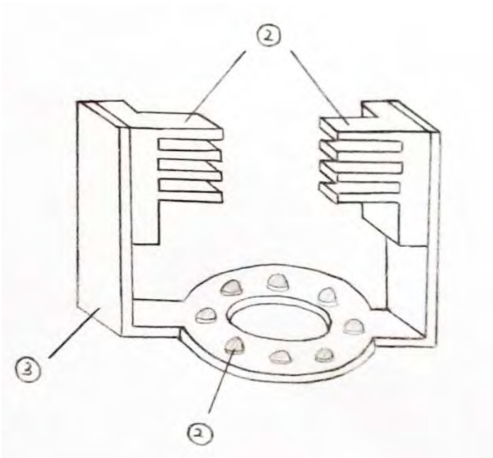


Figure 3.30: Concept Design 3

After prototype testing process, the holder that already made was not suitable. So, the design needs to be modified. The measurement also changed and the holder part needs to be printed again. So, below was the holder design after modification.

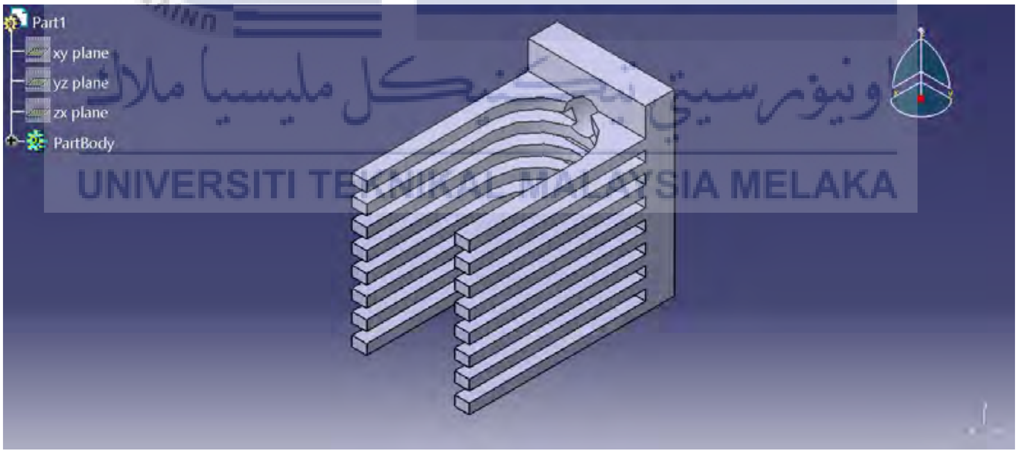


Figure 3.31: Holder of roller in CATIA Software, after modification

The actual design for the roller was made by using CATIA V5 Software for full visual. However, there were few changes of roller arm design due to shape of nozzle blade. It must be fitted and the design was according to the nozzle blade.

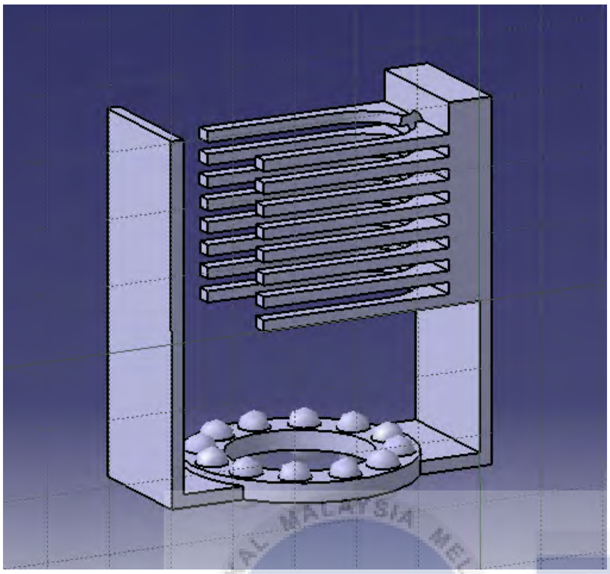


Figure 3.32: The actual design of roller for Kossel 3D printer

Figure 3.33: Prototype of the roller

Prototype testing on Kossel 3D printer was ran and the sample of dog bone was printed for testing process. The holder of the roller and the bracket of the roller were made separately to eases the assembling and disassembling process.

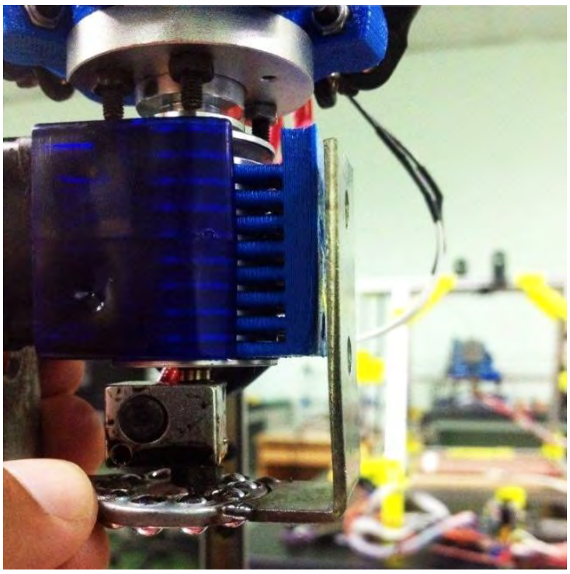


Figure 3.34: Prototype testing on the nozzle of Kossel 3D printer

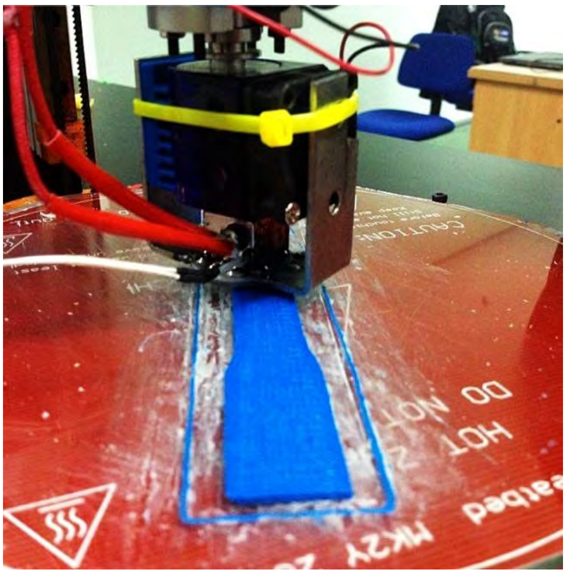


Figure 3.35: Printing a dog bone sample with roller (applied pressure)

The Figure 3.36 shows the close-up view of the roller that attached on the nozzle of the printer. The roller is used to apply the pressure on every filament extruded to the sample.

Figure 3.36: Close-up view of the roller that install on the nozzle

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result

4.1.1 The Experiment

A standard 'dog-bone' sample, ASTM D638, was used as the sample will undergoes several test including tensile test, porosity test, and lastly surface roughness test. There were 14 samples with different parameters that were made by open source 3D printer which is Kossel. The first 14 samples were made using the roller and it was installed onto the printer to produce the samples. Then, it followed by preparing another 14 samples, also with different parameters and it were produced a normal sample without applying pressure to the samples.

Besides, the standard dimension and measurement for dog bone sample of ASTM D638 is 165mm for the length, 19mm for the width and together with thickness of 4mm. On the other hand, while preparing the 14 samples, there were 3 parameters used to differentiate the samples results. The parameters used were layer thickness in milimeter (mm, fill density in percent (%), and printing speed in milimeter over second (mm/s). There were 5 samples made by every parameter used. Unfortunately, for the sample of layer thickness, there are limit thickness for this setting which is until 4mm of layer thickness only can be made. So, the total samples for this parameter were 4 samples only starting from 1mm until 4mm of layer thickness. The rest, still remain the same as 5 samples. In addition, there is no parameter used for pattern spacing due to there was no support structure needed while printing sample.

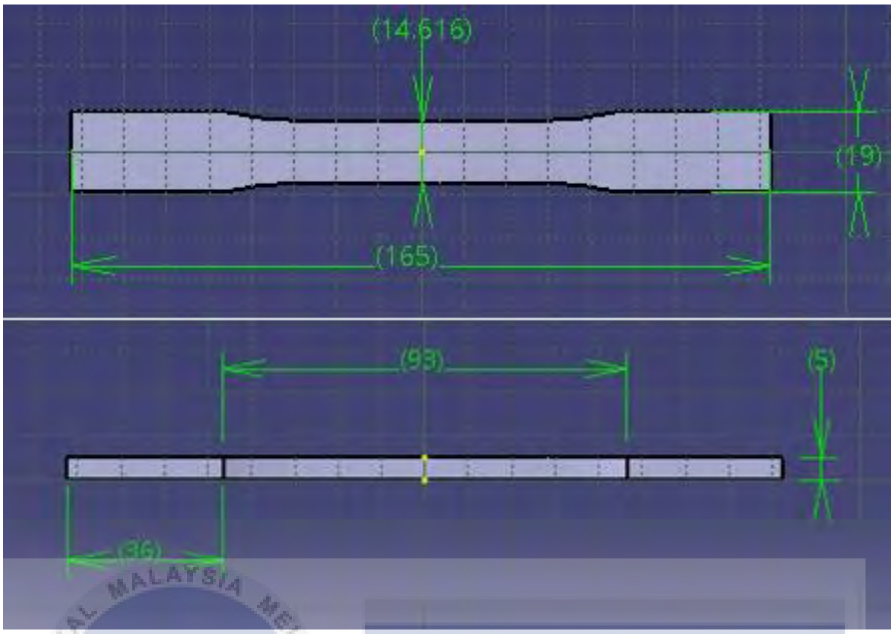


Figure 4.1: Dimension for dog bone sample of ASTM D638

The design of the dog bone was prepared by using CATIA V5 software and then save it as STL file. The format of STL file will transfer into Repetier software for slicing process. The actual 3D drawing or CAD drawing of dog bone sample was shown as diagram below in CATIA V5 software interface.

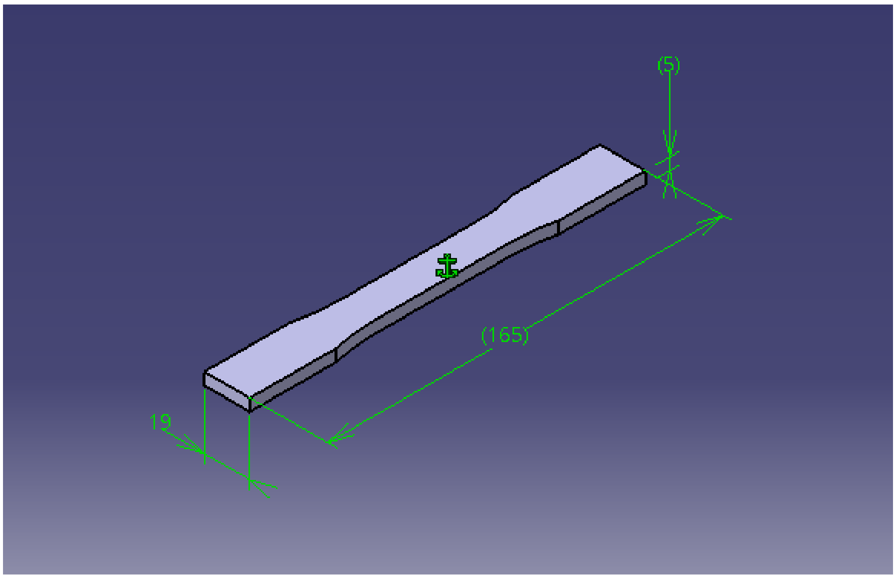


Figure 4.2: CAD drawing for dog bone sample of ASTM D638

In order to produce a sample from parameter of layer thickness, there were 4 samples are made started from 0.1mm, 0.2mm, 0.3mm and 0.4mm. Then, it followed by samples of fill density which is the fill that covered the material or ABS in percentage started from 20%, 40%, 60%, 80% and for the full filling of material, 100%. Lastly, for the speed of printing parameter, the speed used is 20mm/s, 40mm/s, 60mm/s, 80mm/s and 100mm/s. Basically as fixed variables, the standard measurement while varies the samples were the layer thickness of 3mm, 100% fill density and the standard speed of 60mm/s. Thus, for every parameter used, there was only certain measurements such as standard measurement will remain the same.

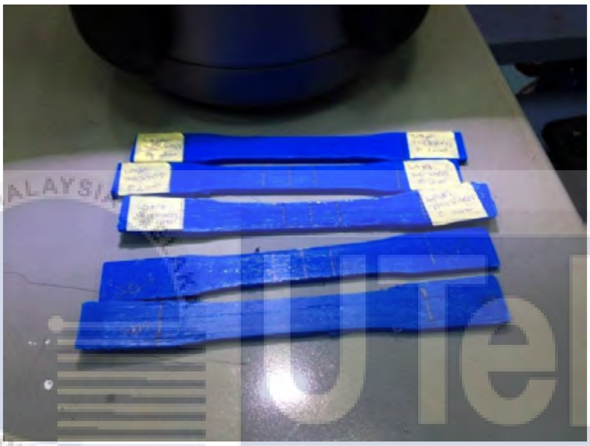


Figure 4.3: Samples of dog bone printed by Kossel 3D printer

4.2 Layer Thickness

4.2.1 Tensile Test

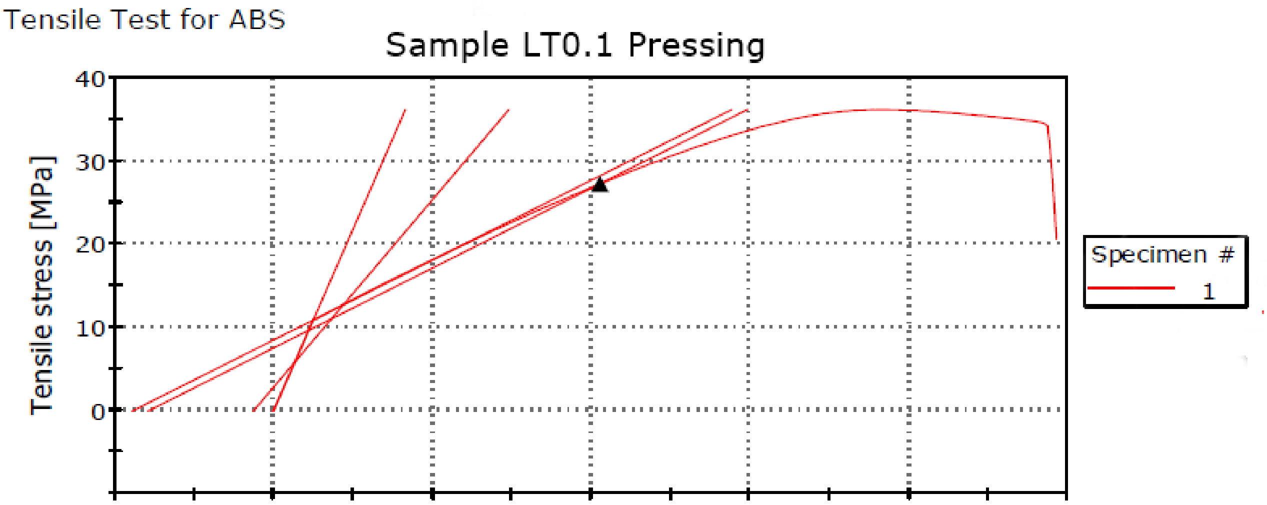


Figure 4.4: Sample of tensile test graph by using Universal Testing Machine (UTM) for sample of 0.1mm layer thickness sample with pressing

Figure 4.5: Sample of dog bone after undergoes tensile test

Table 4.1: Tensile Test result for Normal Sample of Layer Thickness

Layer Thickness [mm]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
0.1	2.1872	31.15	0.03	1087.64
0.2	2.2227	32.36	0.04	1175.87
0.3	1.9462	29.05	0.02	972.69
0.4	2.1982	31.65	0.03	1096.71

Table 4.2: Tensile Test result for Sample with Pressure of Layer Thickness

Layer Thickness [mm]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
0.1	2.3692	35.78	0.04	1108.70
0.2	2.5963	37.16	0.04	1216.03
0.3	2.5031	36.08	0.04	1123.61
0.4	2.6772	34.07	0.05	1091.63

Table 4.1 and 4.2 shows the tensile test results as well as other varieties data collection related to tensile test such as maximum load in kN, tensile stress at load in MPa, tensile strain in mm/mm, and modulus in MPa. In this experiment, the main purpose is to gain the data of tensile stress at load. Thus, the other related data collection also can be present as well. The graph plotted below only involving the

data collection of tensile stress for normal sample and sample with pressure only. The tensile test for the 4 samples of varieties layer thickness was done. The graphs for every data collection from tensile test were plotted such as tensile stress, maximum load, tensile strain and modulus against layer thickness respectively.

Meanwhile, Table 4.2 shows the data collection of tensile test for sample with pressure. The parameter involved is layer thickness.

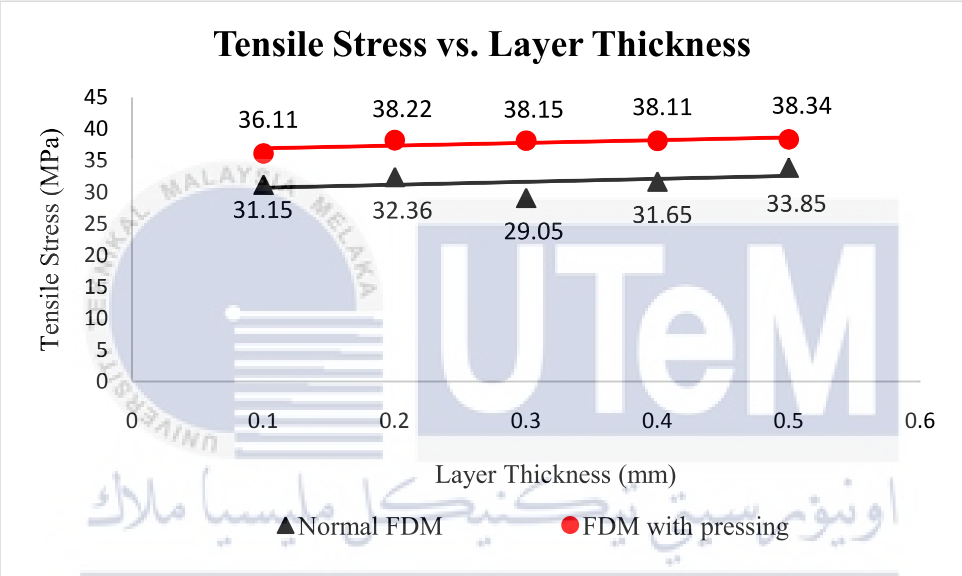


Figure 4.6: Graph of Tensile Stress vs. Layer Thickness for Normal Sample and Sample with Pressing

By referring the graph plotted above, the 'red dot' plotted represents the sample that made with pressing by Kossel 3D printer, while the 'black triangle' plotted represent the normal sample by Kossel 3D printer as well. The tensile strength for normal samples are little bit lower compared to sample that made with pressing. There were improvements made after using or applying pressure on the sample while printing on every layer. It proved that this method, pressing or rolling on the material could improved the mechanical properties of the material used on 3D printer.

4.2.2 Surface Roughness Test

Table 4.3: Surface Roughness of normal sample and sample with pressure for layer thickness

Normal Sample		Sample with Pressure	
Layer Thickness (mm)	Surface Roughness Ra (µm)	Layer Thickness (mm)	Surface Roughness Ra (µm)
0.1	4.526	0.1	3.882
0.2	4.982	0.2	4.190
0.3	6.349	0.3	5.021
0.4	7.760	0.4	6.652

The table above shown the result to make a comparison of surface roughness after undergoes surface roughness test for selected parameter which is layer thickness. Generally, the higher the values of surface roughness (mm), the rougher the surface of the material or printed part. Thus, based on the obtained results, the values of normal sample shown is higher than the sample with pressure. This is due to the pressure applied on every surface including on the tested part which is the top surface of the dog bone sample. The graph of layer thickness against Surface Roughness was plotted to show the comparison between Normal Samples and Samples with pressing made by Kossel 3D printer.

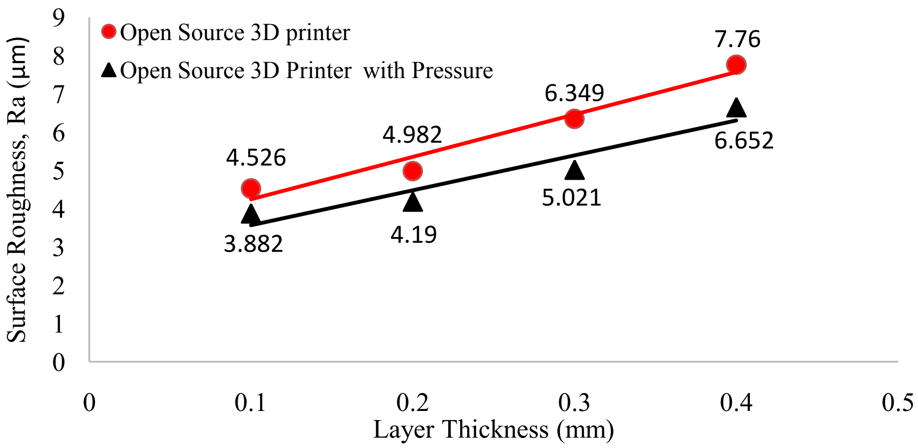


Figure 4.7: Graph of Surface Roughness against Layer Thickness for Normal Sample and Sample with pressure

The open source 3D printer represent the normal sample that produce by Kossel 3D printer, whereas the other one represent the sample produce by Kossel 3D printer with pressure. As stated previously, the values for normal sample will be higher than the improved sample after the sample was applied with pressure. The graph shows, as the values layer thickness is increased, the values of surface roughness also increased.

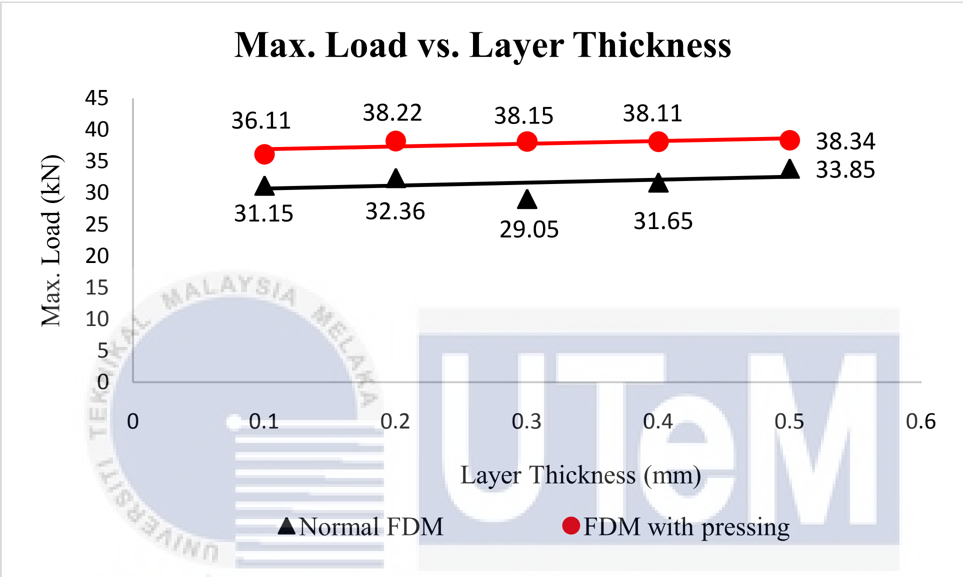


Figure 4.8: Graph of Maximum Load versus Layer Thickness for Normal FDM and FDM with pressing

The maximum load of normal FDM samples after tensile test keeps decreasing. Meanwhile, the maximum load of FDM samples with pressing were slightly higher than normal samples and keep increasing.

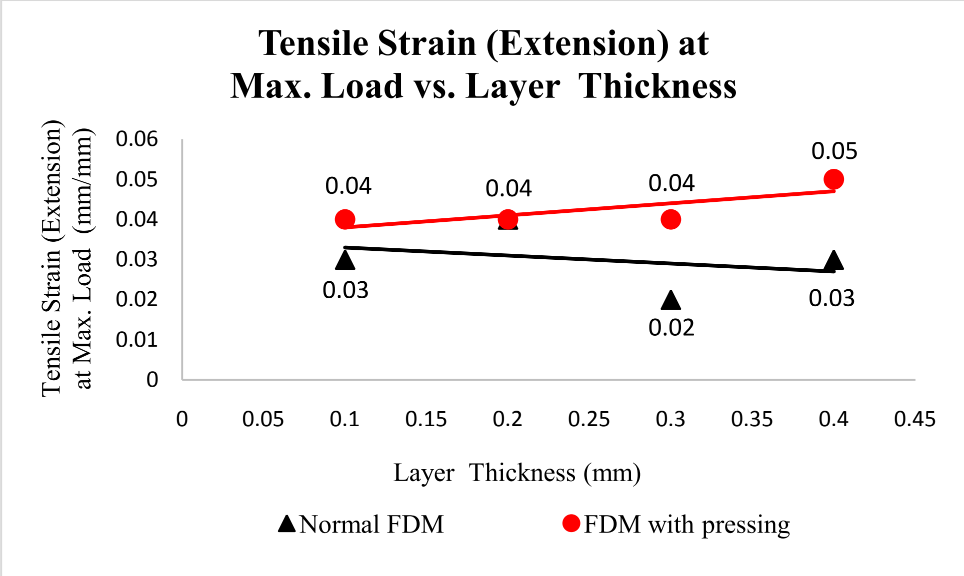


Figure 4.9: Graph of Tensile Strain (Extension) at Maximum Load versus Layer Thickness for Normal FDM and FDM with pressing

Next, for tensile strain (extension) at maximum load for normal FDM samples shows that the values are not increasing uniformly. Then, by comparing the values of tensile strain for samples of FDM with pressing, it shows that the tensile strain are maintain at 0.04 mm/mm from 0.1 mm until 0.03 mm of layer thickness. At last, the last value of layer thickness at 0.4 mm, the tensile strain is increase to 0.05 mm/mm.

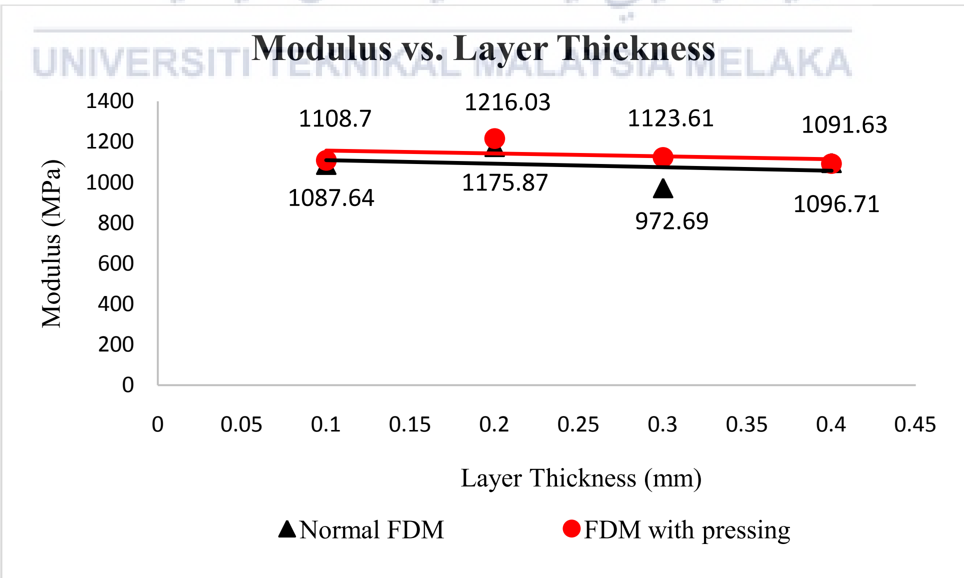


Figure 4.10: Graph of Modulus versus Layer Thickness for Normal FDM and FDM with pressing

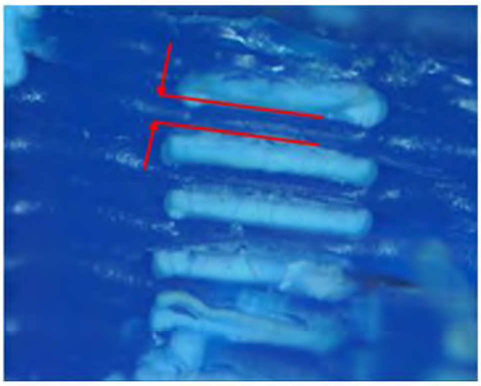
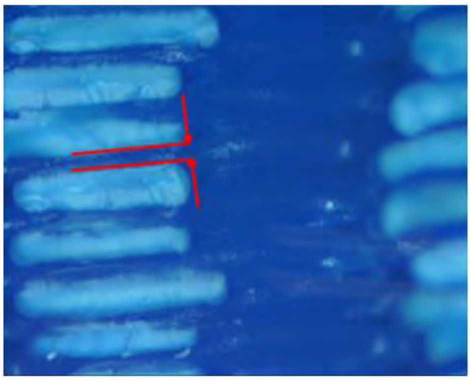
The last data collection from tensile test for layer thickness were recorded which is the modulus in unit of MPa. Based on Figure 4.10, the data modulus against layer thickness for the samples of normal FDM were slightly near to the samples of FDM with pressing data. Only small changes for the modulus but it show the values are improved.

4.2.3 Porosity Test (Optical Microscope)

The experiment of porosity consists of two methods which are method of densities and the other one by using optical microscope. In order to determine the value of density, a simple calculation is needed and the value for percentage of porosity can be obtained by using a simple mathematical calculation. Unfortunately, this method only available for the next parameter which is on fill density samples.

Meanwhile, by using the optical microscope, a view of microstructure from cross-sectional area of the sample can be viewed. This test is available for parameter of layer thickness.

Table 4.4: Porosity Image of 0.1 mm Layer Thickness
for Normal FDM and FDM with pressing samples

	Normal FDM sample	FDM with pressing sample
Layer Thickness of 0.1 mm (300 μm)		

The table 4.4 shows the comparison of porosity image of 0.1mm layer thickness samples for normal FDM and FDM with pressing. The structure of dog bone sample for FDM with pressing was a bit closer compared to the porosity image for normal FDM sample. It means that the sample of FDM with pressing had been compress for every layer printed while producing the dog bone sample. The arrangement of the structure also shows a changes after applying a force or roll on the dog bone sample.

Figure 4.11: Dog bone Sample were cut into several pieces and ready for Porosity test

4.3 Fill Density

4.3.1 Tensile Test

Table 4.5: Tensile Test result for Normal Sample of Fill Density

Fill Density [%]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
20	2.0352	29.79	0.03	989.06
40	2.1019	29.30	0.02	960.17
60	1.9860	29.52	0.03	984.09
80	1.9531	28.81	0.02	911.76
100	2.0344	29.78	0.03	986.35

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

Fill Density [%]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
20	1.9691	29.82	0.03	990.36
40	2.6320	34.53	0.05	1092.44
60	2.5982	34.22	0.04	1073.51
80	2.6712	36.16	0.05	1126.72
100	2.3788	35.58	0.05	1117.68

The tensile test for the 5 samples of varieties fill density was done. The graphs for every data collection from tensile test were plotted such as tensile stress, maximum load, tensile strain and modulus against fill density respectively.

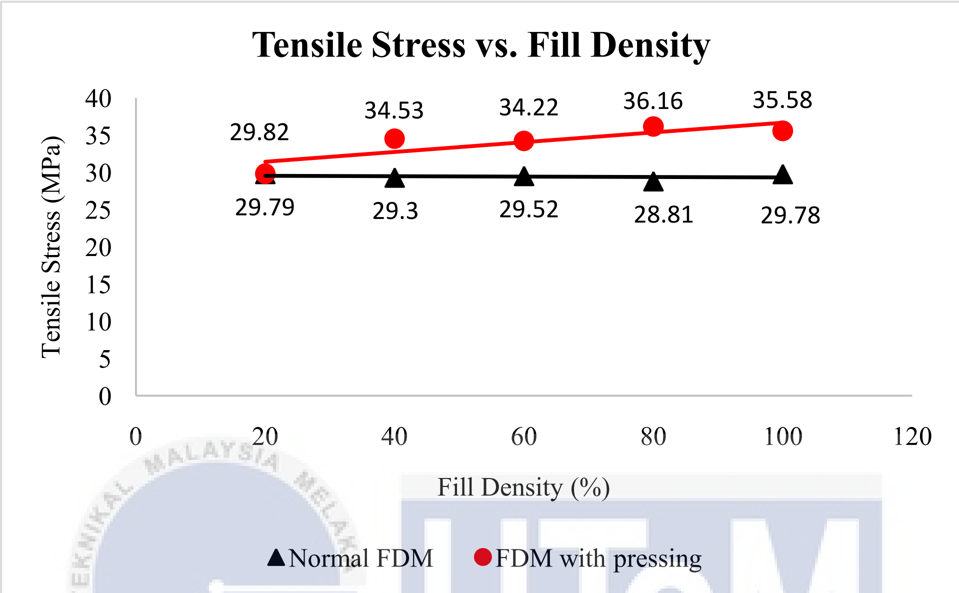


Figure 4.12: Graph of Tensile Stress vs. Fill Density for Normal Sample and Sample with Pressing

The graph plotted on Figure 4.11 shows that the tensile stresses of samples with pressing have higher values. Meanwhile, the normal samples without applying force on the material shows that the data plotted were slightly lower than the samples with pressing. Thus, the tensile stresses for the samples with pressing were quite strong and took a longer time to break during tensile test.

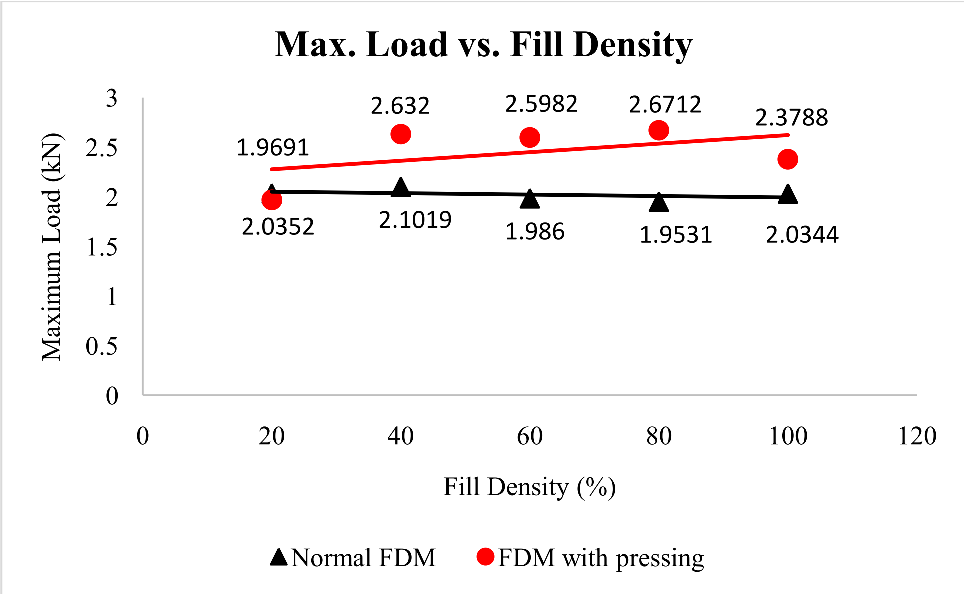


Figure 4.13: Graph of Maximum Load vs. Fill Density for Normal Sample and Sample with Pressing

At first of data plotted for sample with pressing, at 20% of fill density have shows that the maximum load was lower than the normal sample data for maximum load. The data plotted maybe due to the faulty of the printed sample. Most probably at 20% of fill density, the printer was not able to print properly or it was not a suitable variable to be printed by Kossel 3D printer. Overall, the data plotted for Normal Samples and Samples with pressing were at normal range.

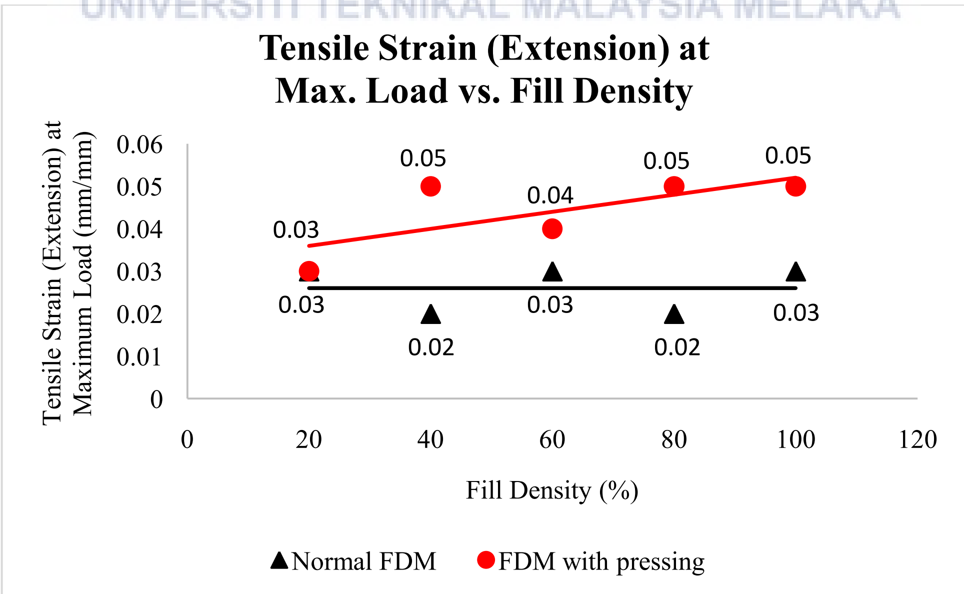


Figure 4.14: Graph of Tensile Strain (Extension) at Maximum Load vs. Fill Density for Normal Sample and Sample with Pressing

The graph of tensile strain against fill density was plotted. The pattern for samples with pressing data shows plotted increasingly. While, the data of normal samples, it shows up and down and uneven.

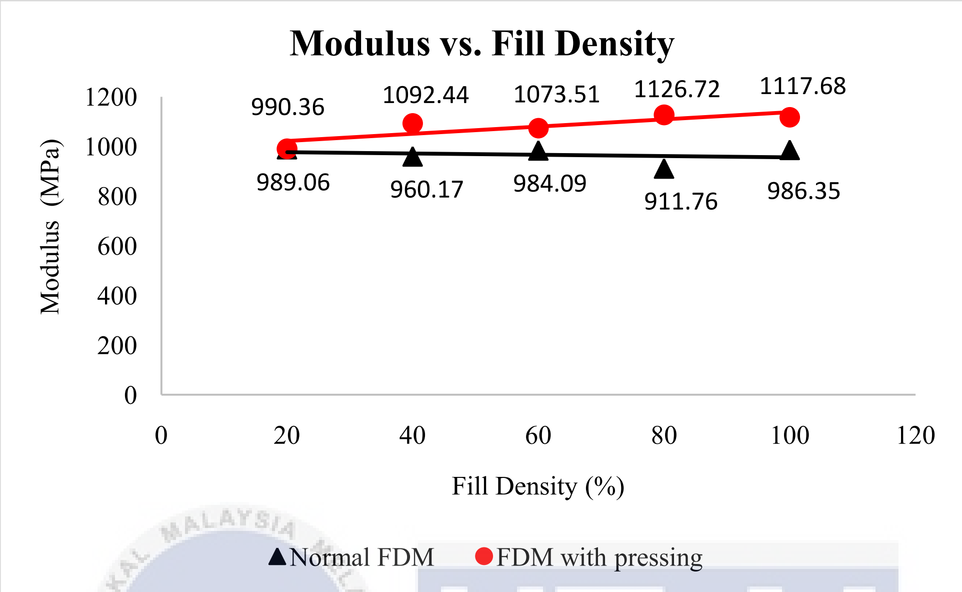


Figure 4.15: Graph of Modulus vs. Fill Density for Normal Sample and Sample with Pressing

Based on Figure 4.15, the result show the modulus for samples with pressing was higher than the normal samples. The modulus for samples with pressing was slowly increasing according to the increasing fill density.

4.3.2 Surface Roughness Test

Table 4.7: Surface Roughness of normal sample and sample with pressure for fill density

Normal Sample		Sample with Pressure	
Fill Density (%)	Surface Roughness Ra (µm)	Fill Density (%)	Surface Roughness Ra (µm)
20	8.378	20	7.667
40	6.991	40	6.349
60	4.860	60	5.979
80	4.118	80	4.601
100	3.976	100	4.742

The graph of fill density against surface roughness was plotted to show the comparison between normal samples and samples with pressing made by Kossel 3D printer.

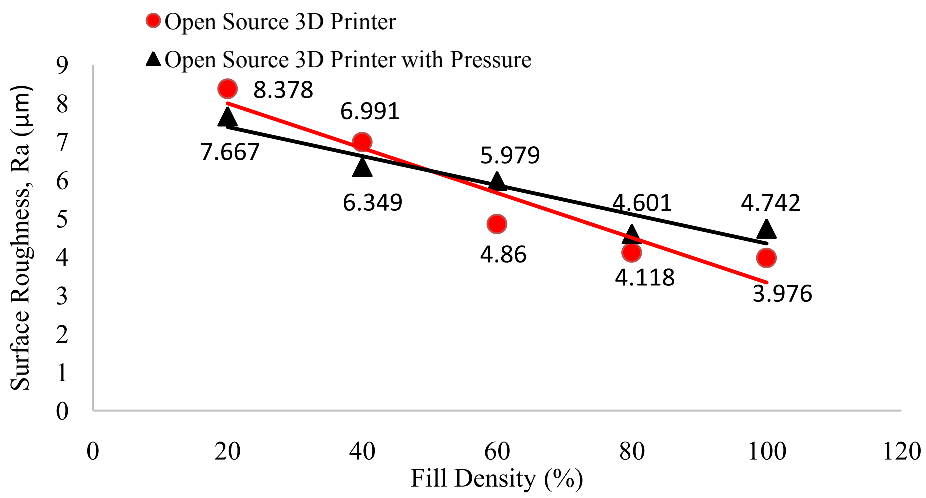


Figure 4.16: Graph of Surface Roughness against Fill Density for Normal Sample and Sample with pressing

4.3.3 Porosity (Theoretical Calculation)

Method of densities by experiment was used in order to determine the theoretical value for percentage of porosity. As mention in Chapter 3 previously, the formula involved are shown as following:

$$\textit{Sample Density} = \frac{Mass\ of\ Sample}{Volume\ \ of\ Sample} \qquad (1)$$

$$\textit{Percentage of Porosity} = \left[1 - \frac{Sample\ \ Density}{Material\ \ Density}\right] \text{x } (100) \qquad (2)$$

Material's Density (ABS) = 1.04 $^{g}/_{cm^3}$

Table 4.8: Porosity Table of Normal FDM Sample for Fill Density

Fill Density, %	Mass, g	Volume, cm^3	Density, cm^3	Porosity, %
20	0.4219	0.9	0.4688	54.92
40	0.5701	1.0	0.5701	45.18
60	0.7197	1.0	0.7197	30.80
80	0.7628	1.0	0.7628	26.65
100	0.8198	1.0	0.8198	21.17

Table 4.9: Porosity Table of FDM Sample with pressing for Fill Density

Fill Density, %	Mass, g	Volume, cm^3	Density, cm^3	Porosity, %
20	0.4671	0.9	0.5190	50.10
40	0.6114	1.0	0.6114	41.21
60	0.7326	1.0	0.7326	29.55
80	0.7981	1.0	0.7981	23.26
100	0.8418	1.0	0.8418	19.06

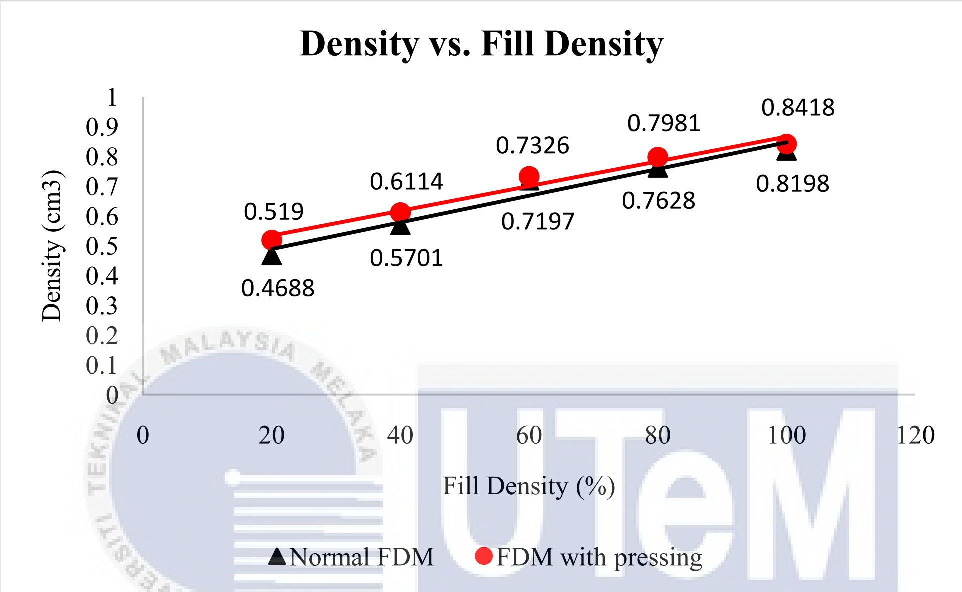


Figure 4.17: Graph of Density against Fill Density
for Normal Sample and Sample with pressing

The graph of density against fill density was made to see the flow of the data. As it shown in graph, most of the data for sample with pressing were located slightly higher than normal sample data. It means that the densities of samples with pressing were bit heavy compared to the densities of normal samples. When the percentage of fill density is higher, the value of density will be higher as well. The mass of the material is divided with the density of ABS which is 1.04 g/cm^3.

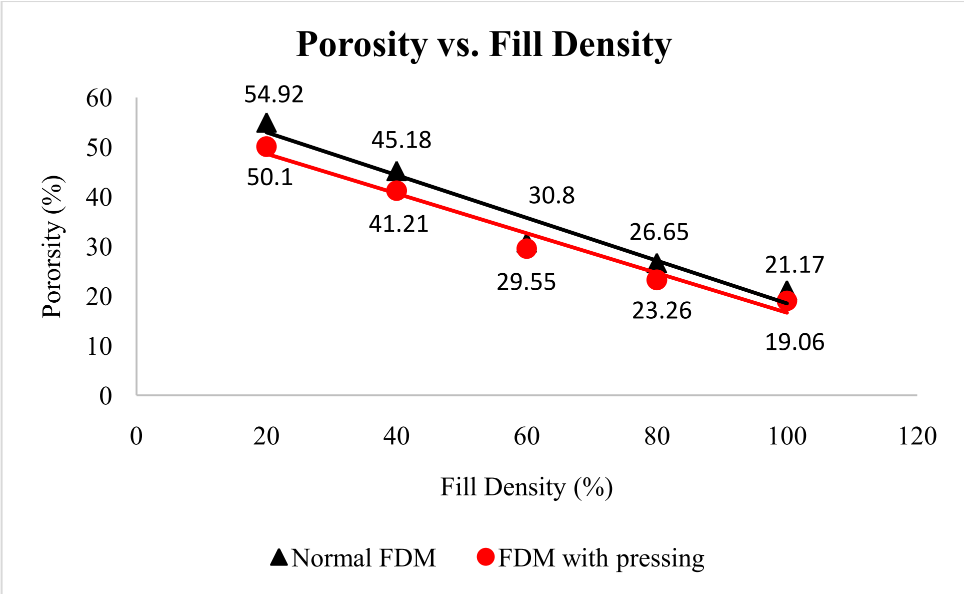


Figure 4.18: Graph of Porosity against Fill Density
for Normal Sample and Sample with pressing

Related to the density data calculated previously, if the values of densities are higher, thus the values of porosities will be lower. The fill density represent on how much the material will fill in the printed part and it also can be increases due to the force applied on the material while printing process. Thus, the sample becomes compressed and the mechanical properties of the sample may increase as well. Based on the plotted graph on Figure 4.17, the percentage of porosity for samples with pressing are lower compared to the normal samples. The particles inside of the sample become closer and the density of the sample also increases. The different for every fill density is small. However, the values of porosity after improvement of the material, it shows positive changes in order to improve the mechanical properties of the sample.

4.4 Printing Speed

4.4.1 Tensile Test

Table 4.10: Tensile Test result for Normal Sample of Printing Speed

Printing Speed [mm/s]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
20	1.9881	30.54	0.03	1053.11
40	2.1954	31.54	0.03	1089.87
60	2.2213	32.64	0.03	1170.53
80	2.6503	34.73	0.04	1108.64
100	1.9573	29.20	0.02	977.02

Table 4.11: Tensile Test result for Sample with Pressure of Printing Speed

Printing Speed [mm/s]	Maximum Load [kN]	Tensile Stress at Load [MPa]	Tensile Strain (Extension) at Maximum Load [mm/mm]	Modulus (Automatic) [MPa]
20	1.9704	30.33	0.03	1049.11
40	2.1972	31.61	0.03	1101.73
60	2.5031	36.08	0.04	1123.61
80	2.7120	34.87	0.04	1120.13
100	2.6762	34.10	0.04	1097.52

The tensile test for the 5 samples of varieties printing speeds was done. The graphs for every data collection from tensile test were plotted such as tensile stress, maximum load, tensile strain and modulus against printing speed respectively.

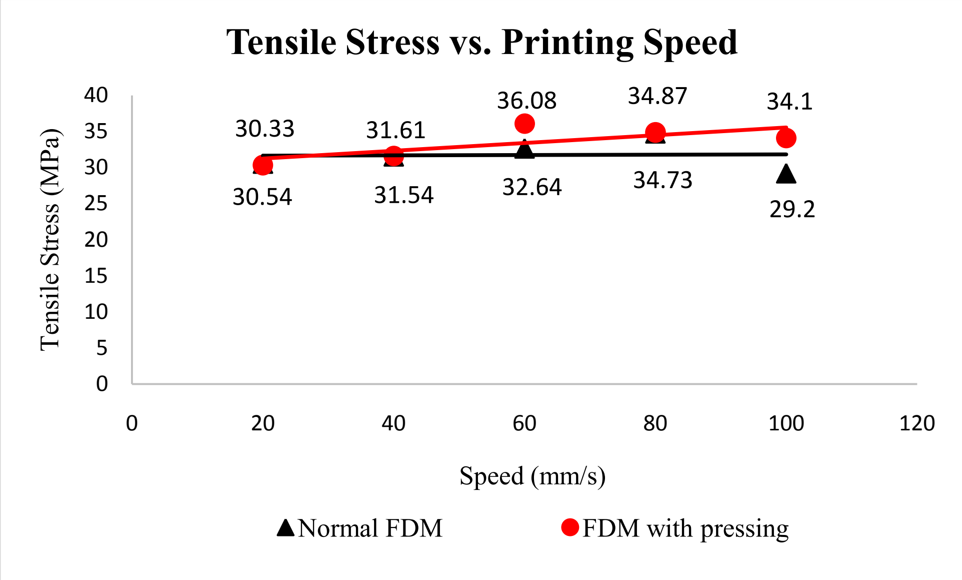


Figure 4.19: Graph of Tensile Stress against Printing Speed for Normal Sample and Sample with pressing

The tensile stress for samples with pressing was slowly increasing by speed. Meanwhile, the tensile stress for normal samples plotted was increasing at 20 mm/s until 80 mm/s and lastly it was suddenly dropped with 29.2 MPa at 100 mm/s. This is maybe due to the high speed of printing and the time taken for the melted filament (ABS) become shorter than usual. Thus, it may affect the quality of the sample.

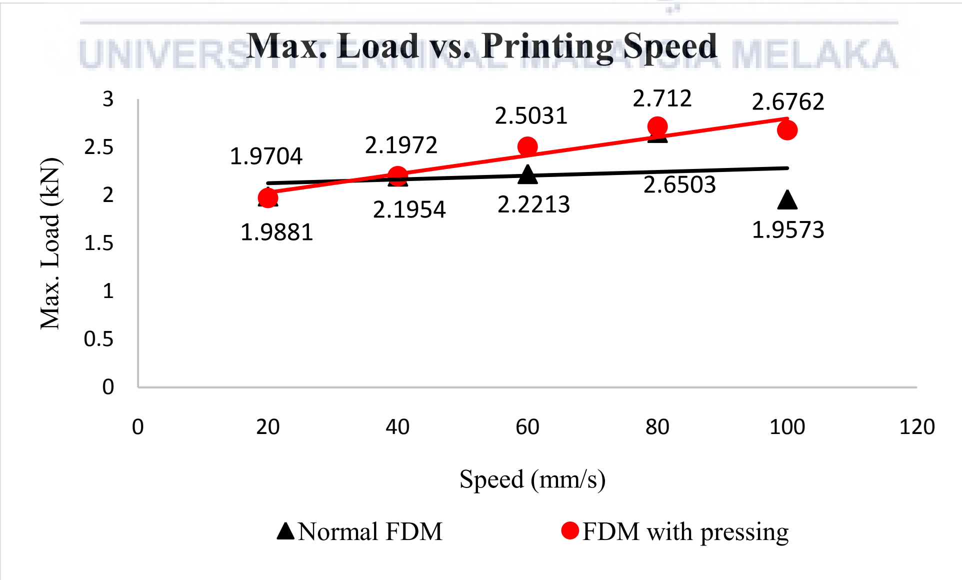


Figure 4.20: Graph of Maximum Load against Printing Speed for Normal Sample and Sample with pressing

The graph of maximum load versus printing speed was plotted and the sample with pressing was slowly increasing. Then, for the normal sample data shows that the maximum load increasing and suddenly dropped at 100 mm/s.

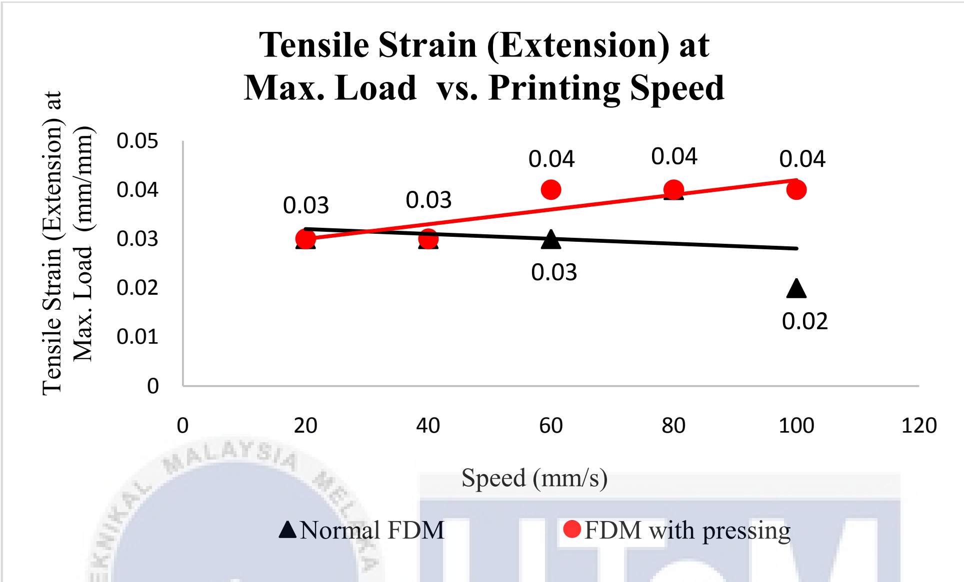


Figure 4.21: Graph of Tensile Strain (Extension) at Maximum Load against Printing Speed for Normal Sample and Sample with pressing

The data for sample with pressing shows the tensile strain at maximum load plotted increasingly, while the normal sample data plotted remained at 0.03 mm/mm until 60 mm/s and there was up and down at the end of the speed of printing process.

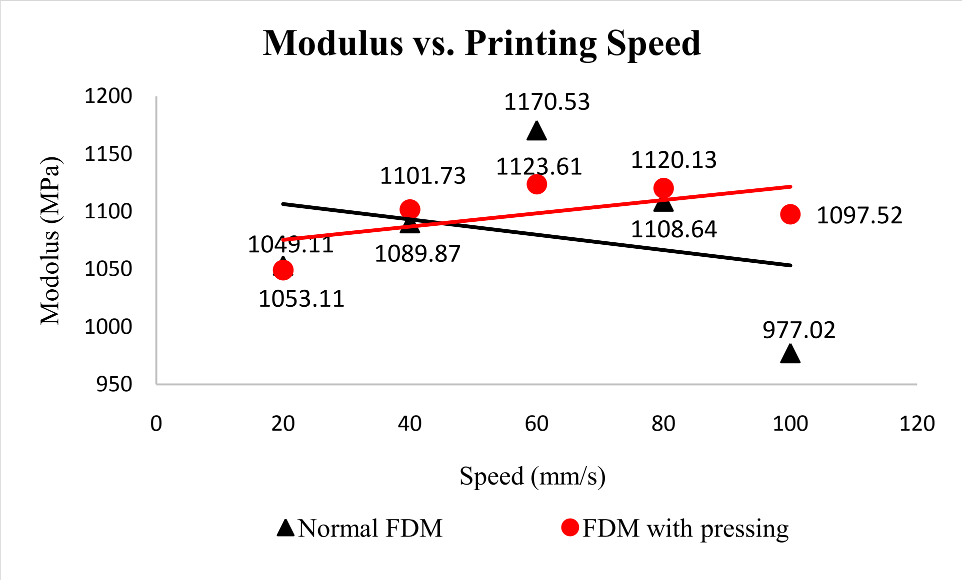


Figure 4.22: Graph of Modulus against
Printing Speed for Normal Sample and Sample with pressing

Lastly, the graph of modulus versus speed of printing that shows uneven plotted graph. The graph of modulus plotted for sample with pressing was increasing until 80 mm/s and dropped at 100 mm/s. A simple conclusion can be made for printing speed parameter, at high speed of printing, Kossel 3D printer was not able to print properly for a better quality of sample.

4.4.2 Surface Roughness Test

The graph of printing speed against surface roughness was plotted to show the comparison between normal samples and samples with pressing made by Kossel 3D printer.

Table 4.12: Surface Roughness of normal sample and sample with pressure for fill density

Normal Sample		Sample with Pressure	
Speed of printing (mm/s)	Surface Roughness Ra (μm)	Speed of printing (mm/s)	Surface Roughness Ra (μm)
20	3.882	20	3.631
40	4.19	40	3.561
60	4.173	60	3.943
80	4.322	80	4.128
100	5.225	100	5.572

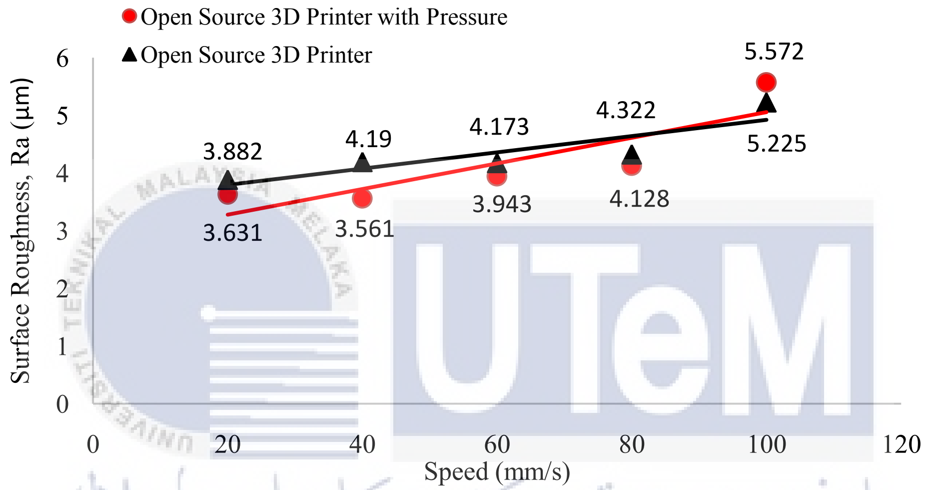


Figure 4.23: Graph Surface Roughness against
Printing Speed for Normal Sample and Sample with pressing

The graph shows the comparison between the surface roughness of normal sample as and sample with pressing also represent as open source 3D printer and open source 3D printer with pressure respectively. The graph plotted for both samples shows that the surface roughness values keep increasing by speed. It means that, as the speed increases, the surface of the sample become rougher. However, the data of surface roughness for sample with pressure was slightly lower or smooth than the normal samples data.

4.5 Discussions

There are few parameters were involved in order to obtain data and results from the several test including tensile test, surface roughness test, and porosity test. Layer thickness of the filament printed on the sample shows that in the tensile test, the tensile stress keep increasing as the layer thickness is increasing. As the layer thickness is getting higher, the maximum load, tensile strain and modulus for both types of sample are increasing. However, based on the results obtained, for the sample with pressing, the strength of the material had been improved a lot based on the tensile test. Meanwhile, the surface roughness of layer thickness for samples with pressing had been improvised compared to the normal samples. On top of that, as the layer thickness increases, the surface roughness of the samples will increases as well and becomes rougher. Besides of these two tests ran, there was another test to view the composition and structure arrangement for cross-sectional area of the dog bone sample. The result shows there was same structure arrangement for sample of 0.1 mm layer thickness for normal sample and also sample with pressing. The only different can be seen on the image was distance between the structure. The compressed sample shows a closer structure arrangement compared to normal sample with a bit far from each other.

The fill density plays the main role in order to achieve a good standard sample or 3D printed part. After the sample undergoes tensile test, the result shows for normal samples made by Kossel 3D printer were remained at the same level around 28Mpa to 29MPa. While, data plotted for sample with pressing was slowly increasing as the fill density approaching to 100%. Tensile strain is the extension of the filament at the break point as the result of the maximum load given. 100% of fill density gives the maximum load as the filament printed on the sample become closer to each other. This may affect the sample to be stronger and hard to break. The structure arrangement of the sample at 100% of fill density was closely pack together, while for the 20% of fill density the structure arrangement was far from each other. Thus, the lower the percentage of fill density of printed part, the higher the possible of the sample to break faster. Surface roughness for both types of samples shows the same results where the surface roughness decreases as the percentage of fill density is approaching to 100%. Besides, there were simple calculations made to determine the value of density and the percentages of porosity for fill density. First, the data obtained from calculation was the value of density. The density of the sample increases as the percentage of the fill density increases. The constant density for normal ABS material is 1.04 g/cm^3. A stronger sample is made with higher density. Thus, the percentage of porosity may decreases due closer structure arrangement. By comparing the percentage of porosity, the samples with pressing had less porosity.

A variety of printing speed had different surface roughness result compared to fill density. The faster the speed of printing, the higher the surface roughness of the sample. It is mean, the faster printing speed produce a rough surface. The results for both types of sample were same. It gives a smooth surface as the sample printed with slow speed. For instance, to print the first and last layer of sample, the minimum speed must be 30 mm/s then followed by 60 mm/s for the following layers. It is advisable to set the speed between 30 mm/s until 60 mm/s for better quality of printing. The higher speed of printing may affect the quality of the sample. But, in term of produce a sample, it will take a longer time to print the part. Meanwhile, the usage of roller shows an improvement of surface roughness compared to the normal samples. The surface of sample with pressing was a bit smoother, but not too much. The result for tensile test shows that the minimum speed has a good tensile stress. It occurred for both types of sample. The speed that needs to print the sample must be at low speed, so that the nozzle can extrude the filament nicely towards each other. Based on the results, as the speed used greater than 60 mm/s, the quality of the sample will be lower. The usage of roller with high speed of printing did not help the improvement of strength of the sample. Unless, the speed used is lower, then the roller will work properly to improve the structure arrangement of the sample while printing.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a conclusion, this case study involving a preparation of roller that uses to apply pressure onto the material to be printed on the sample. The improvement of mechanical properties of material used which is ABS, had been made and the results were obtained from several tests such as tensile test, surface roughness test, and porosity test. Based on the obtained result, the graph of tensile stress was plotted to see the pattern of the experiment. It shows that the strength of the sample was improved after the force is applied onto the sample while printing. The parameters used in this project were layer thickness, fill density and speed of printing. Therefore, for every parameter used, there were 5 samples was made. Unfortunately, for the layer thickness, there was some limitation of the printer. The Kossel 3D printer only able to print with maximum layer thickness of 0.4mm layer thickness. Thus, the samples for layer thickness are 0.1 mm, 0.2 mm, 0.3 mm and 0.4 mm. Then, for the fill density and speed of printing, there were 5 samples were made for every parameter. Therefore, the samples made by normal Kossel 3D printer were 14 samples, while the other 14 samples were made by Kossel 3D printer with roller. The total samples for both types were 28 samples.

The sample with pressure applied while printing shows the best result as it tested on tensile test, surface roughness test and porosity test. However, there was error occurred on measurement for samples with applied pressure. The surface roughness of the sample is based on the speed of printing. It should be better if speed of printing used in between 20 mm/s and 60 mm/s. At this range of speed, the nozzle is able to extrude the filament (ABS) properly and the structure arrangement of the filament printed will closely pack together. High speed of printing is not recommended for printing setting. This is due to printing method while the filament is extruded on the heat bed or on the layer of material. Thus, due to high speed of printing, the sample may experience low quality of strength. Tensile test was done for every parameter used and the results shows there were improvement made after the sample was applied with pressure. The tensile stress increasing slowly.

5.2 Recommendations

While preparing the samples, it was found that the Kossel 3D printer was not able to print at several setting changes based on the parameter used. Especially while printing the sample for speed of printing setting. At 80 mm/s and 100 mm/s of printing speed, the filament extruded from the nozzle had a problem to stick onto the existence layers. As mention in discussion on Chapter 4, the usage of printing speed was not suitable. In addition, the temperature also plays a main role while printing process. The environment of the room should be at the range of standard room temperature instead of in a air-condition room. It may affect the nozzle temperature. Thus, the extruded filament temperature and nozzle temperature may drop easily.

Based on the experiment while printing the sample, it was found that the design of the roller that installed on the nozzle keep changes. A few modifications were made to fit in the roller and the design keep changes. The design of the roller was improvised in order to ease the process of assemble and disassemble. The holder of the roller was made separately with the bracket of the roller. During the printing process, the cooling fan was not fully functional to cooling down the nozzle. Thus, the cooling process was not done properly due to the instalment of the roller in between of every nozzle blade. In future, the design for the roller holder should be improvised to install near to the filament extruder.

Lastly, by applying a method of pressing, the actual dimension of the sample may reduce after produce the sample. Thus, it is recommended for the future research to include the percentage of length and width reduction due to pressure applied. The measurement of the dog bone sample should be recorded for normal sample and sample with applied pressure to determine the percentage of length reduction.

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