PRODUCTION OF 3D PRINTED PLA MATERIAL FOR MEDICAL PHANTOM IN RADIOTHERAPY

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PRODUCTION OF 3D PRINTED PLA MATERIAL FOR MEDICAL PHANTOM IN RADIOTHERAPY

By

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Dissertation submitted in partial fulfilment of the requirement for

the degree of Bachelor of Health Science

(Honours) (Medical Radiation)

July 2020

CERTIFICATE

This is to certify that the dissertation entitled "PRODUCTION OF 3D PRINTED PLA MATERIAL FOR MEDICAL PHANTOM IN RADIOTHERAPY" is the bona fide records of research work done by Ms AIMAN RASYIDAH BINTI MOHD RAHIMI during period Sept 2019 to Aug 2020 under my supervision. I have read this dissertation and that is my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Health Science (Honours) (Medical Radiation).

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I hereby declare that this dissertation is the result of my investigation, except where otherwise stated and duly acknowledged. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at Universiti Sains Malaysia or other institutions. I grant Universiti Sains Malaysia the right to use the dissertation for teaching, research and promotional purposes.

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LIST OF ABBREVIATIONS

Name	Definition
AM-RPs	Additive manufacturing radiotherapy phantom
3D	Three-dimensional
2D	Two-dimensional
ABS	Acrylonitrile butadiene
CAD	Computer-aided design
CNC	Computer numerical control
FDM	Fused deposition modelling
GLTF	Graphics Library Transmission Format
OBJ	Object
PLA	Polylactic acid
SLA	Stereolithography
SLS	Selective laser sintering
STL	Stereolitography
STL	Standard Tessellation Language
TPU	Thermoplastic urethane

LIST OF SYMBOLS

cm^2	centimetre square
electron/cm^3	electron per centimetre cube
g/cm3	gram per centimetre cube
mm	millimetre

ABSTRAK

Tujuan utama kajian ini adalah untuk menghasilkan fantom cetakan 3D berbentuk slab menggunakan bahan plastik PLA (polylactic acid). Dua objekif khusus yang lain adalah untuk mereka bentuk dan memotong model menggunakan perisian pemodelan dan perisian pemotong dan untuk melihat perbezaan ketumpatan dalaman dalam peratus 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% dan 100% dengan menggunakan perisian pemotong. Alatan yang digunakan dalam kajian ini adalah bahan plastik PLA, perisian CAD (Thinkercad), perisian pemotong (Cura), dan pencetak jenis MyVista Cube 200. Langkah pertama, permodelan objek telah direka bentuk menggunakan Thinkercad. Kemudian, model tersebut telah disimpan dalam bentuk fail STL dan telah di eksport ke perisian Cura. Selain itu, beberapa parameter pencetak telah ditetapkan dan model tersebut telah di potong kepada beberapa helaian melintang menggunakan perisian Cura. Akhir sekali, pencetakan 3D bahan plastik PLA dicetak menggunakan pencetak 3D jenis MyVista Cube 200. Keputusan menunjukkan fantom cetakan 3D menggunakan bahan plastik PLA berjaya dibentuk dengan menggunakan aplikasi Thinkercad dan telah berjaya dicetak dengan kualiti fabrikasi yang bagus. Selain itu, geometri dalaman oleh perisian Cura menunjukkan ruang atau jarak dalaman antara plastik semakin mengecil apabila peratus ketumpatan dalaman fantom semakin meningkat. Kesimpulannya, fantom cetakan 3D dengan ketumpatan 30% berjaya dihasilkan untuk digunakan dengan meluas dalam penyelidikan radioterapi dosimetri.

ABSTRACT

The objective of this study is to produce 3D printed phantom in slab size using polylactic acid (PLA) material. The other two specific objectives are to design and slice the model using available modelling and slicing software and to compare the internal geometry of PLA between infill densities of 10%, 20% 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% using slicing software (Cura). The materials in this study included PLA material, CAD software (Thinkercad), slicing software (Cura) and MyVista Cube 200 printer. The process of 3D printing was initially conducted by using CAD software that was used for object modelling. Then, the model was saved in STL file and was directly exported to slicing software. The printing parameters have been inserted and the model was sliced into horizontal layers to estimate the time taken needed in printing. Then, the process of 3D printing was done by using MyVista Cube 200 printer. The results shows that the 3D model was successfully designed using Thinkercad, and being printed in slab size with good fabrication quality. Besides, the internal geometry illustrated in Cura software show that the space or gap between the materials decrease with infill densities. As a conclusion, the 3D printed PLA phantom of 30% of infill density was successfully made that can be used for dosimetry in radiotherapy for further study.

CHAPTER 1

INTRODUCTION

1.1 Background of study

The idea of additive manufacturing or 3D printing material technologist was first emerged by Charles Hull in 1987 (Wohlers and Gornet, 2014). He was the first man who patented stereolithography (SLA) in creating models by curing a liquid photopolymer resin using ultraviolet lasers. Since then, tremendous progress has been made such the used of extrusion in making thermoplastic object material layer by layer from bottom to top that is known as fused deposition modeling (FDM). Nowadays, these technologies attract many inventors from other fields included medical field in producing additive manufacturing radiotherapy phantom (AM-RPs) or three-dimensional (3D) printed phantom. The statistics show the growth rate of purchasing 3D printed phantom products increasing by 25% during the 25 years before 2010 and by 27% between the years 2010 and 2012 (Mitsouras *et al.,* 2015).

Additive manufacturing processess made by different printing techniques such as stereolithography (SLA), Selective laser sintering (SLS) and fusing deposition modeling (FDM). SLA uses ultraviolet light laser to turn liquid resin into hardened plastic in a process called photopolymerization. This method has high accuracy, produce good surface quality, energy, and able to fabricate complex shape of model, however, it is lack of expensive equipment and materials and requires the design of support for manufacturing process (Ma, 2013). SLS printing uses a high-powered laser to fuse polymer powder to produce complex geometry model in a short amount of time. The laser is used to stack the layers together and the layer is then lowered and covered by new powder until all of the model's cross sections have been finished (Koo *et al.*, 2017).

Besides, FDM printing uses the extrusion of heated thermoplastic filaments to built a model. It uses a layer-by-layer deposition technique, in which thermoplastic filament is extruded through a nozzle, and stack together with the materials on the previous layer (Bettinger *et al.*, 2007). Each technology develops different materials features in terms of durability, strength, flexibility and even costs. Usually, affordable materials would bring a good choice for customers especially for specific clinical and research purposes (Hazelaar *et al.*, 2018).

FDM printing is the most suitable technique used in printing thermoplastic material such as acrylonitrile buadiene styrene (ABS), polylactic acid (PLA), polycarbonate (PC), thermoplastic urethane (TPU), polyphenylsulfone (PPSF), and more. This is because, thermoplastic meterials are good to endure heat, chemical and mechanical stress. Besides, each plastic has its own melting point to withstand with heat. FDM is most high demand technology to used in various industries in making plactic-based product from automaotive, medical to consumer product industries. In 3D printing, FDM is the most cheap and cost-effective compared to other printing technique and suitable to used in research. However, there are several limitations as it has lowest dimensional accuracy and resolution for the complex prototype. Besides, the end product is likely to produce visible line on its surface. Then, post processing is needed for the consumers demand for the smooth surface.

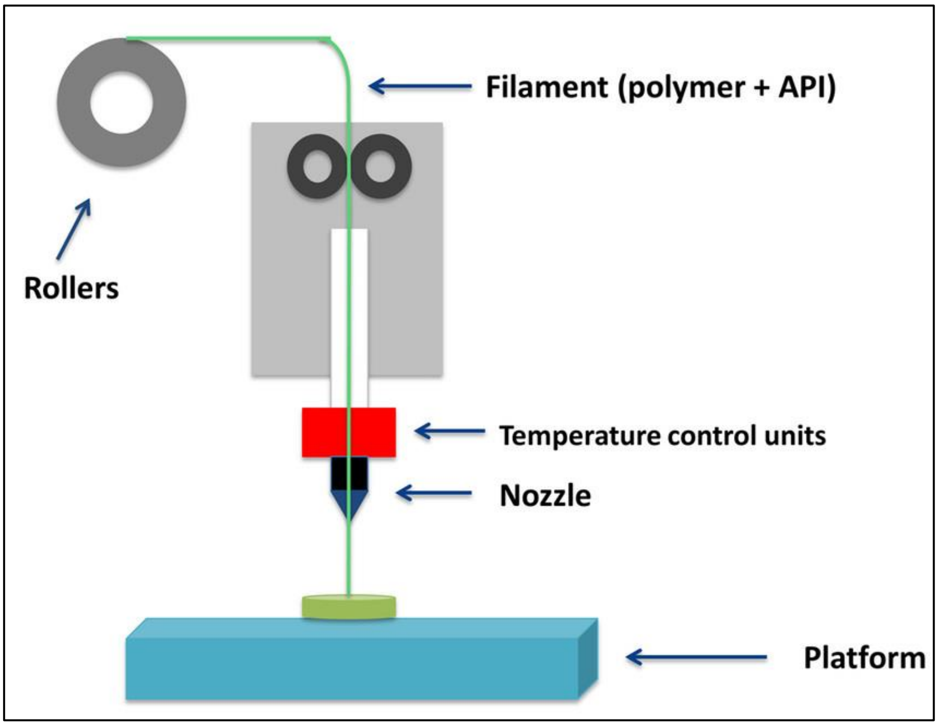

Figure 1: FDM 3D printing technology (Koo et al., 2017).

The 3D printing PLA material with various infill densities can be set on the printing parameters available in the printing software. The infill density defines the amount of plastic material used in the production of the object. High infill density means there would be a large amount of material use and vice versa. Besides, high infill density governs small amount of air gaps between each component of material that leads to produce high strength objects. In radiotherapy, the production of 3D printed phantom with different infill density could employ variety tissue densities represent the organs in human body such as muscle, fat, bone and lung. Okkalidis et al (2018) have investigated that the infill densities of PLA material of about 30%, 90%, and 100% enable to produce Hounsfield unit (HU) equivalent to lung, fat, and muscle respectively. This shows that the composition of lung has large amount of air compared to other organs. Figure 1.2 shows the ineternal geometry of PLA material of 5%, 10%, 15%, 25%, 40%, 50%, 60%, 75%, 90%, and 100% infill densities.

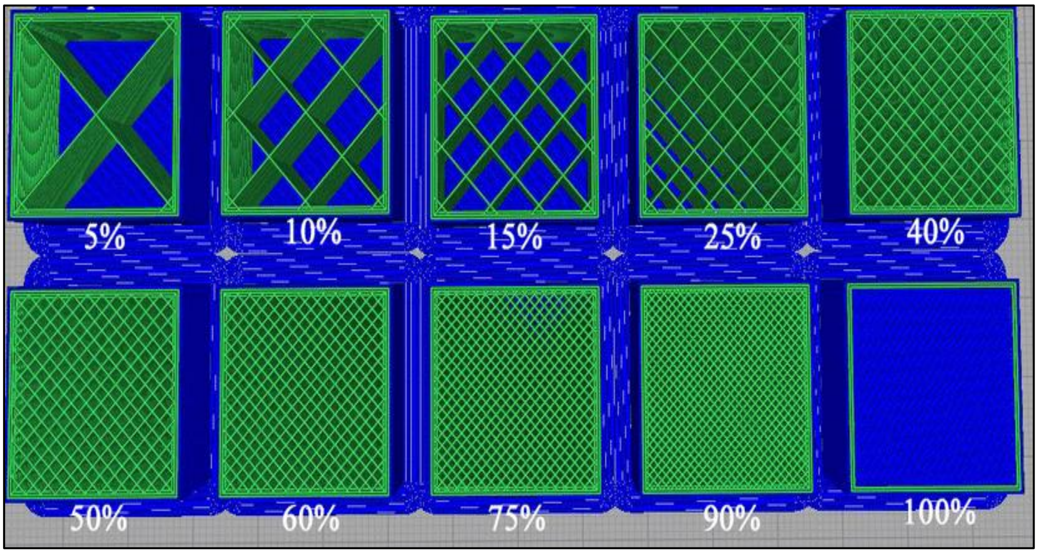

Figure 2: The internal geometry of PLA material with 5%, 10%, 15%, 25%, 40%, 50%, 60%, 75%, 90%, and 100% infill densities (Carlino and Messina)

In this study, the phantom was design with a dimension of $12\times12cm^2$ with thickness of 1cm. The design of this model was made with computer-aided design (CAD) software, Thinkercad. From CAD, the 3D model was saved in 3D format Standard Triangulation Language, STL file and was exported to slicing software (Cura software) to insert printing parameters. The STL file format only describes 3D model's surface geometry and was useful for the slicing software to communicate with CAD software. The 3D model was sliced into 2D image as it would be easier for the printer to interpret the data and print the model by parts. MyVista Cube 200 3D printer was used to print out 3D printed PLA phantoms. This printer applied fused deposition modelling technique as it used heat to melt the PLA filament to form extruded layers from bottom to top. However, only the 3D printed PLA slab phantom of 30% infill density was able to print.

The other infill densities of 10%, 20%, 40%, 50%, 60%, 70%, 80%, 90% and 100% were unable to complete cause of limitation of time due to restriction during COVID-19.

1.2 Problem of statement

Commercial homogeneous solid water phantom has still being used as a radiotherapy phantoms, which not totally represent the heterogeneity of the human body that consists of various types of tissue densities such as bone, skin, lung and muscle. This would give inaccurate dose delivery to the patient and would contribute limitation in accomodating individual patient's pathological features (Tino *et al.*, 2019). Besides, manufacturing water phantom is costly, heavy and inconvenient to use for the user. These disadvantages would bring limitations in terms of work efficiency and time management. Hence, the intention of this study is to produce phantom made from PLA material in variation of infill densities which can be useful for dosimetry test in radiotherapy for further study.

1.3 Significant of study

The significant of the study is to produce a 3D printed phantom using PLA material which are cheap and has density of 1.2 that close to water. Hence, this phantom would be potentially useful in clinical for dosimetry purpose in radiotherapy.

1.4 Research objectives

General objective:

- This study aims to produce 3D printed phantom in slab size using PLA material.

Specific objectives:

1. To design and slice the model using Thinkercad and Cura software.
2. To compare the internal geometry of PLA between infill densities of 10%, 20% 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% using slicing software.

CHAPTER 2

LITERATURE REVIEW

2.1 Additive manufacturing (AM) technology techniques

3D printing technique or AM technology techniques can be clasify into Fused deposition modelling (FDM), Selective Laser Sintering (SLS) and stereolithography (SLA) techniques. In FDM technique, PLA filament material of 100-200HU is heated and immediately harden to create an accumulating layer by layer 3D object from bottom to top (Jeong *et al.*, 2015). Then, the model was taken by the slicing software (Slic3r 1.2.9) and combine the model with all parameters needed. Lastly, the phantoms were coated with a low-viscosity epoxy casting resin. Exposy resin was used as a coating because it has high degree of resistance to physical abuse, superior fatique strength and ability to cure over a wide range of temperature (Craver and Carraher, 2000).

Next, Liu et. al (2019) used as stereolithography (SLA) or polyject technique to print the 3D printed phantom for their study of Biomimetic 3D-printed neurovascular phantoms for near-infrared fluorescence imaging. In this technique, the ultraviolet (UV) light laser was used to form a required geometry of phantom by a commercial printer (Objet260 Connex3, Stratasys Inc., Eden Prairie, MN). The UV laser was used to harden a powder from the surface to form 3D object (Provaggi and Kalaskar, 2017). Then, the hardened surface was lowered one stage layer to allow a new layer to cover the other layers sections. After that, the prototype was then post-cured in an ultraviolet curing apparatus to allow final polymerization (Schaub *et al.*, 1997).

Lastly, Selective Laser Sintering (SLS) also was the technique used in 3D printing technologies. Fina et. al (2017) have used SLS technique in their study of 3D printing of medicibes. They added 3% of Candurin1 Gold Sheen into the powder as an absorbent to allow printability of the powder. The mixture was then transferred to the SLS printer to produce the phantom. A high-power CO2 laser beam scans the surface of the powder bed in a specific 2D pattern, selectively sintering the powder particles and building the 3D object in a layer by layer fashion (Provaggi and Kalaskar, 2017).

2.2 Infill density

Infill density defines the amount of plastic used inside the print and it relates to the strength, printing duration and weight of the object. Different Infill density of the material governs the different amount of air gap between raster (Keat *et al.*, 2019). High infill density of the materials would give a small of air gaps between the materials and stronger in terms of strength. Meanwhile small infill density governs a large of air gaps that would decline the strength of the material. Each infill density might able to represent the different variations of human tissues such as lung which have the composition of air between tissues, and bone which is more likely to compact with hard tissues.

Aloyaydi *et al.,* (2019) has investigated the study with a topic of the influence of infill density on microstructure and flexural behavior of 3D printed PLA parts processed using FDM printing. In the study, the infill density of 40%, 60%, 80%, and 100% of PLA material has been tested. The result shows that the stiffness of PLA sample increasing as the infill density increase. PLA sample of 80% and 100% infill density shows raised the toughness compared to 40% and 60%. This is because, the layer between the raster in contact closely resulted in small porosity between each raster.

Besides, Ricotti *et al.,* (2017) have investigated the dosimetric characterisation of 3D printed bolus at different infill percentages (10%, 20%, 40% and 60%) for external photon beam radiotherapy. The purpose of their study was to investigate the shift of the build-up region in photon beam with the presence of different densities in PLA and ABS materials. The HU unit of all the densities was analyzed after scanned with Optima CT 580 RT scanner (GE Healthcare, Waukesha, WI, US) operating at 120 kVp. The result shows bolus with high infill density would have higher median HU while large interquartile range for low infill density. For the same infill density, PLA boluses has higher density than ABS boluses. PLA boluses Dmax shifted from 12 mm to 12 mm, 8 mm, and 0 mm when 10%, 20%, 40%, and 60% were used. Meanwhile, Dmax shifted from 12 mm to 11 mm, 8 mm and 2 mm for ABS boluses when 10%, 20%, 40% and 60% were used.

2.3 Common 3D printing materials used in radiotherapy

The common materials used for 3D printed phantom in radiotherapy are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). The previous study stated that both materials have been confirmed to have similar properties to the water. This statement is proved by investigation of the physical density of ABS and PLA are 1.04 g/cm^3 and 1.2 g/cm^3 and electron density of 3.38 x 10^{23} electrons/cm^3 and 3.80 x 10^{23} electron/cm^3 respectively (Burleson *et al.*, 2015). Thus, PLA and ABS phantoms are said to be water-equivalent phantom and suitable to use for dosimetric purposes in radiotherapy. Moreover, PLA material is a plastic polymer that is odorless and required lower-heated energy compared to ABS materials. In contrast, ABS material is more durable and able to withstand high temperatures (Alssabbagh *et al.*, 2017). The properties of ABS and PLA, an FDM printer can build slanted walls without using other support materials to prevent from falling (Xie and Chen, 2017).

Besides, thermoplastic polyurethane (TPU) also have been proved for the use of 3D bolus in radiotherapy. This is because, (TPU) has a density of 1.13 g/cm^3 which is near to the water density (Atiqah *et al.*, 2019). Besides, TPU has excellent tensile elasticity, high elongation, and good load-bearing capacity compared to materials PLA and ABS. It is because it has properties in between the characteristics of rubber and plastics that offer flexibility (Polyurethane.americanchemistry.com, 2019). Furthermore, the previous study found that TPU materials were suitable to mimic eye lens, heart, liver, and skin in terms of elemental compositions, physical density and mass attenuation (Alssabbagh *et al.*, 2017). Then, Craft et al. have investigated that the Hounsfield unit (HU) of TPU material is similar to the white and gray matter of human brain tissue. Nowadays, the current research for TPU materials is more towards the fabrication of skin because of excellent conformity and elasticity.

2.4 The applications of 3D printed phantom in radiotherapy

2.4.1 Quality Assurance

Quality assurance in radiotherapy is crucial to prevent errors in delivering dose to patients. It was used to ensure consistency of medical prescription, safe fulfillment of dose prescription to the target volume and gives minimal dose to surrounding affected tissues of patients (Thwaites *et al.*, 2005). Besides, the use of 3D printed phantom in radiotherapy have developed widely. This is because the physical characteristics of the materials itself are much easier to handle, light, and versatile compared to commercial phantom that is heavy and inconvenient to use.

The previous study has investigated the use of 3D printed materials polylactic acid (PLA) in producing head phantom for vivo dosimetry in quality assurance of radiotherapy. This study has been made by Kamomae et al (2017). In this study, they conclude the PLA material was practicable for artificial in vivo dosimetry in quality assurance of radiotherapy. This is because they found the dosimetric comparison between calculated TPS and measured dose, and the percentage dose difference between 3D printed phantom and anthropomorphic phantoms were only within $\pm$5% for single static field irradiation and Volumetric modulated arc therapy, VMAT plan.

Moreover, Kim et al (2017) have used 3D printed acrylic polymer materials for patient-specific quality assurance in radiotherapy. Patient-specific phantom was made 3D allow morphology and structural features of the spine-shaped of the patient. The density of spine modeling process using acrylic polymer was 1.29±1.39 g/cm^3 which was slightly the same to the real spine of humans which is ranged from 0.75 to 1.86 g/cm^3 for both men and women (Bruno *et al.*, 2014). In study, they used DLP and Polyjet printed technologies to produce high-density spine phantom. The printed techniques depend on the materials, the printing parameter such as speed layer thickness, laser power, build orientation, stiffness density, the performance of final fabricate parts and cost (Sandeep and Chhabra, 2017). In conclusion, they found out that the 3D printed plastic materials with a density of around 1.4 g/cm^3 can be used for patient-specific quality assurance for Stereotactic body radiation therapy, SBRT.

2.4.2 Dosimetric characterisation

Dosimetry in radiotherapy is important to confirm the measurement or calculation of prescribed dose absorbed by the patient body. This method is done by using devices called a dosimeter. Many types of dosimeters usually used in radiotherapy such as ionization chamber (IC), thermoluminescence detector (TLD), optically stimulated luminescene (OSL), radiochromic film, radiographic film, metal-oxide semiconductor field effect transistor (MOSFET) dosimeter, and silicone diode dosimetry system. Each dosimeter has its properties according to their accuracy and precision, linearity, dose rate dependence, energy response, directional dependence and spatial resolution (Ravotti, 2018). In radiotherapy, the exact knowledge of the absorbed dose to water at a specific point and its spatial distribution are important, as well as deriving the dose to an organ of interest in the patient (Izewska and Rajan, 2005). The development of 3D printing technologies in the medical field gives opportunities for the use of dosimetric properties in the radiotherapy field.

In the previous study, Kumar et al. have (2010) used ionisation chamber (IC), radiochromic film, and thermoluminescent dosimeter (TLD) to compare the measurement of dosimetric properties between ABS material phantom and Scanditronix-Wellhofer IMRT RW3 phantom. They found the measured dose values between ABS phantom and RW3 phantom using the ionisation chamber (IC), film, and TLD was within 2%. 0.6% and 2.8% respectively in comparison with the TPS calculated dose as reference. Besides, radiographic film agrees 3%/3mm gamma-index evaluation in the region of interest with planned dose distribution. This shows that ABS materials can be used for dosimetry purposes for 1D, 2D, and 3D in radiotherapy.

Besides, Alssabbagh et al. (2017) used TLD and optically stimulated luminescence (OSL) to measure the dosimetric properties of polylactic acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG), Thermoplastic Elastomer (TPE), and Polyamide (PA). The purpose was to evaluate which of these materials have most equivalent to human thyroid. As a result, they found that PLA material was the best choice to produce thyroid phantom. This is because, the elemental composition, CT numbers and mass attenuation coefficient of PLA material matched with human thyroid. In this study, the HU number of PLA materials was 132.4±35.2 that was taken using 120 kVp. This shows the close values to the human thyroid that is ranging 118HU to 125HU using the same applied voltage (Kamijo, 1994)

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 PLA material

Polylactic (PLA) material is used to produce 3D printing object. PLA material has characteristics of strong, thermoplastic, biodegradable, multi-color, and cost-efficient. It is made from the sugars in corn starch, cassava, or sugarcane (Renee, 2017). Besides, It has a physical density of 1.2 g/cm^3 and electron density of 3.80 x 10^{23} electron/cm^3 (Burleson *et al.*, 2015). Hence, it is suitable as an alternative to use as the dosimetry phantoms in radiotherapy. FDM method is used to print out the material.

3.1.2 3-Dimensional modelling (CAD) software

Thinkercad was used as 3D computer-aided design (CAD) tool from Autodesk. Thinkercad was launched by former google engineer Kai Backman and his cofounder Mikko Mononen in 2013 (Carlota, 2020). It runs free and easy to use to create simple designs such as box, circle, cylinder, and other simple shapes. Beforehand, the design can be created by registering in the application using an email. It provides various shapes and colors to choose for model design, angle control, and tools such as ruler and workplane as build base of the model. Also, the basic shape can combine with each other, duplicate, and make holes to design other interesting 3D models. Besides, the information and tutorial can easily be found from https://www.tinkercad.com/things website to make ease for the beginner to follow. Other than that, Thinkercad provides three different 3D format files for saving which are STL, OBJ, and GLTF. In this study, the designed 3D model was saved in STL as this format was capable to communicate with slicing software. Figures 3 and 4 show the front page and the internal view of Thinkercad.

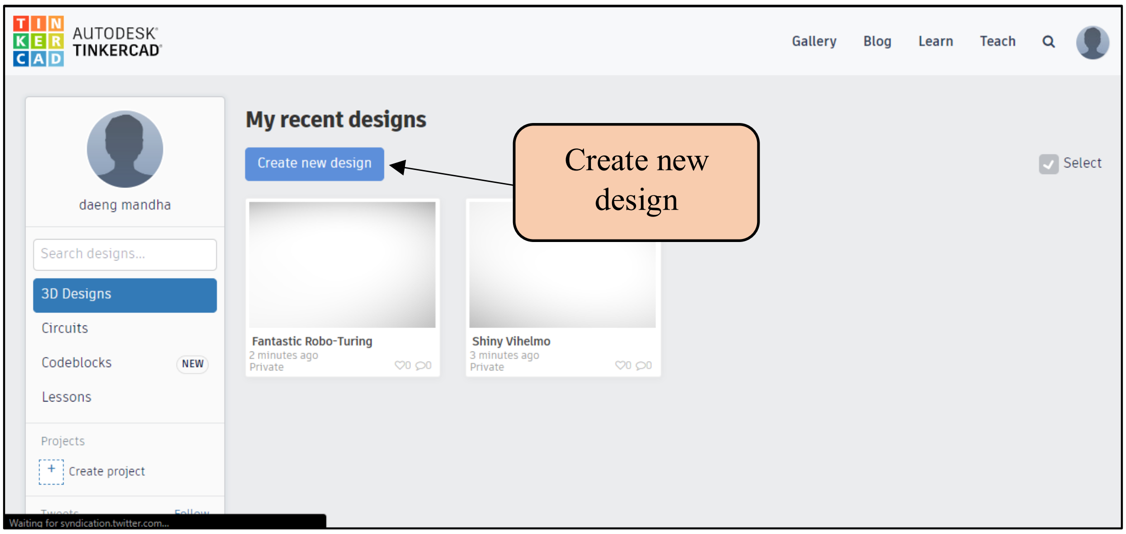

Figure 3: The front page in Thinkercad app

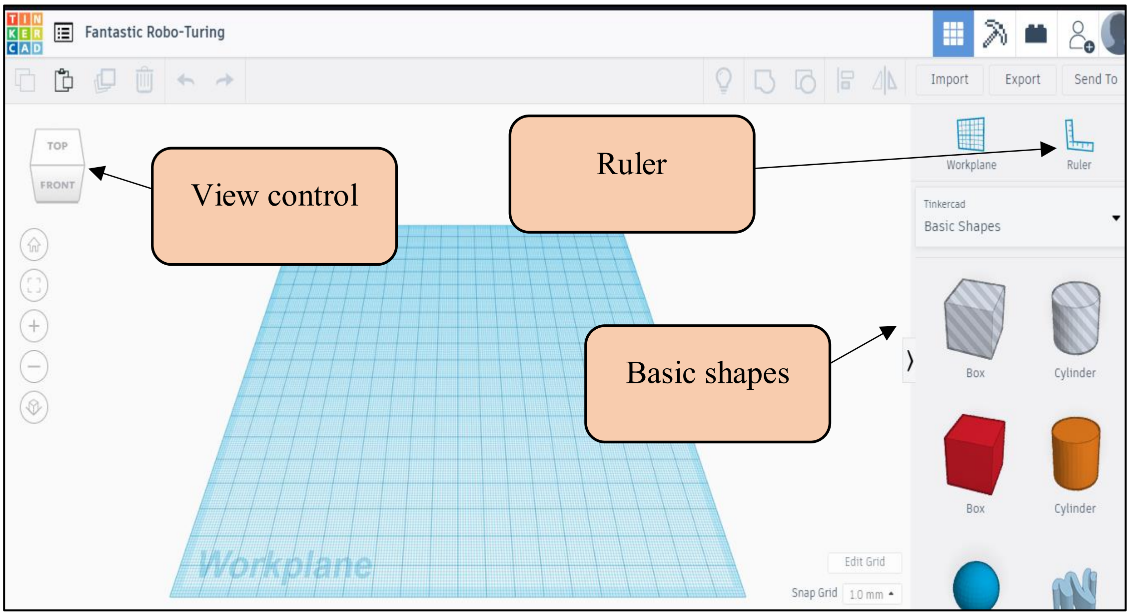

Figure 4: The internal view of Thinkercad

3.1.3 3D printing slicing software

Cura version 4.6.1 was used as 3D printing slicing software produced by Ultimaker. The 3D STL file format from the CAD software was exported in Cura software for the slicing process. This software was not just can be used for Ultimaker printers, but also applicable for other printers as long as the model can be interpreted and saved in STL file format. Technically, it was very handy to use, easy to adapt, and can be downloaded free from Ultimaker website. In addition, the user also can get the information and instruction on how to apply directly from YouTube channel. Specifically, this software works by slicing the model into several layers before converting it into a G-code file. The G-code was generally a computer numerical control (CNC) programming language to instruct machines for a specific function. In other words, the function of slicing software was useful for the printer to print each layer of the object easier describing as linear movement (3Dnatives, 2020). Other than that, this software provides printing parameters as it can be chosen manually to produce what kind of structure of the 3D object to be printed. The basic printing parameters that can be found in this software were extrusion temperature, printing speed, infill density, layer height, shell thickness, bottom and top thickness, filament diameter, nozzle size, infill pattern, and retraction. Figure 5 shows the interior view of Cura software.

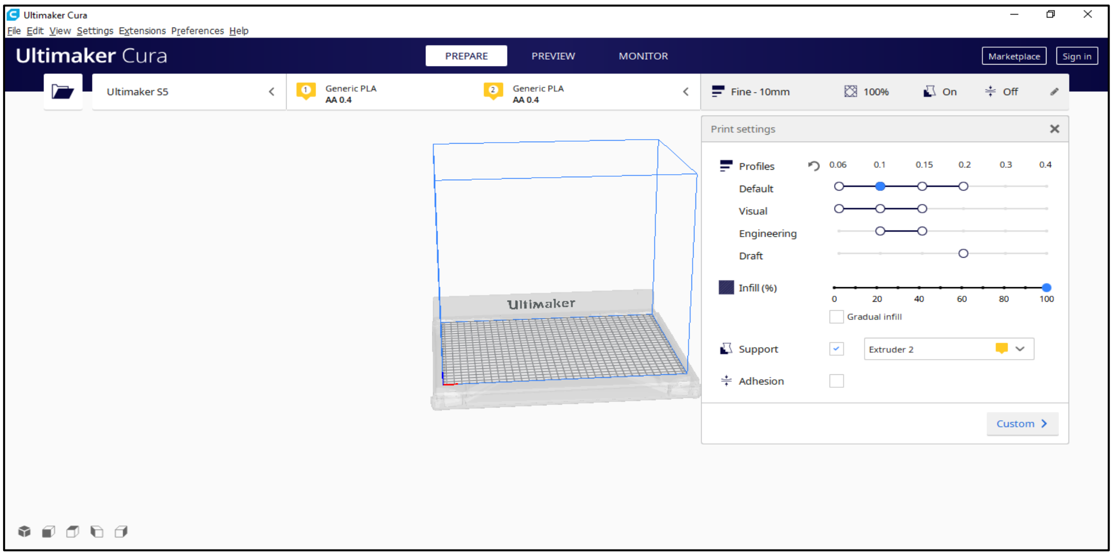

Figure 5: The interior view of Cura software

3.1.4 MyVista Cube 200 3D printer

MyVista Cube 200 3D printer was used to print out 3D printed PLA material. Fused Deposition Modelling (FDM) printing technique was applied for creating this product. This technique uses the extrusion of heated thermoplastic filaments of PLA to generate 3D printed phantom layer by layer from the bottom to the top. The 2D model from slicing software was imported to the 3D STL file format to communicate with the 3D printer. MyVista Cube 200 printer enables producing a 3D printed object size with a maximum of 200 mm x 200 mm x 200 mm. This printer provides the layer height setting from 0.1 to 0.4 mm, and the nozzle diameter of this printer was 0.4mm and can be set as low as 0.1mm of each layer. Besides, the filament diameter available to be inserted in the 3D printer was 1.75 mm. The infill density of 10%, 20%, 30%, 40%, 50%, 60% 70%, 80% 90% and 100% for each phantom also can be set from the printer. The type of plastic material that suitable to use with this printer includes Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA) filament, and Thermoplastic polyurethane (TPU) filament

(Hassan *et al.*, 2020). Figure 6 shows the MyVista Cube 200 3D printer that was used in 3D printing.

Figure 6: MyVista Cube 200 3D printer

3.2 Methods

3.2.1 Design the model using Thinkercad

The printing process began with computer-aided design (CAD) software, Thinkercad. This software was suitable to use for the beginner as the user can experience to create a model by free. The model's design was made by dragging a box shape to the workplane. The box was adjusted to the center to acquired good views when design. The ruler was chosen which provided at the top right of the page to measure a model with a dimension of $12 \times 12 cm^2$ and thickness 1cm. The model also was viewed with every angle located at the top left of the page to ensure the box allocates parallel with the plane and not floating. The color of the model also can be chosen depending on user interest. In this study, the blue color was chosen to match with the PLA filament color to be used. Then, the model was converted in STL file and available to export directly to the Cura software. Figure 7, 8 and 9 shows the position of a box shape chosen from the basic shapes column before the color was chosen, the measurement of the model using ruler, and the OBJ, STL, and GLTF 3D format files available in Thinkercad software.

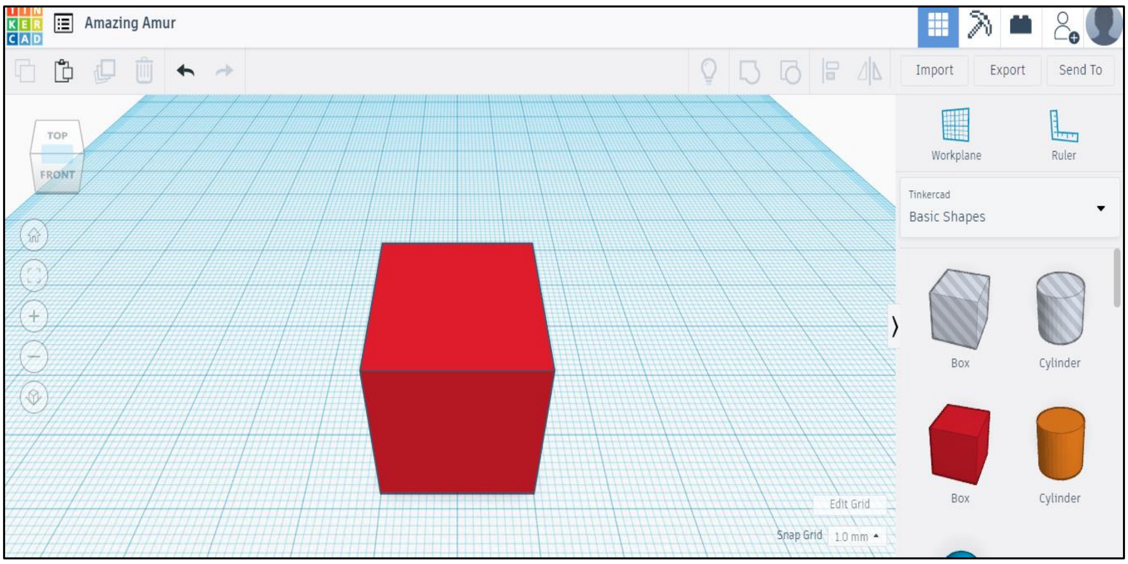

Figure 7: The position of a box shape chosen from the basic shapes column before the color was chosen

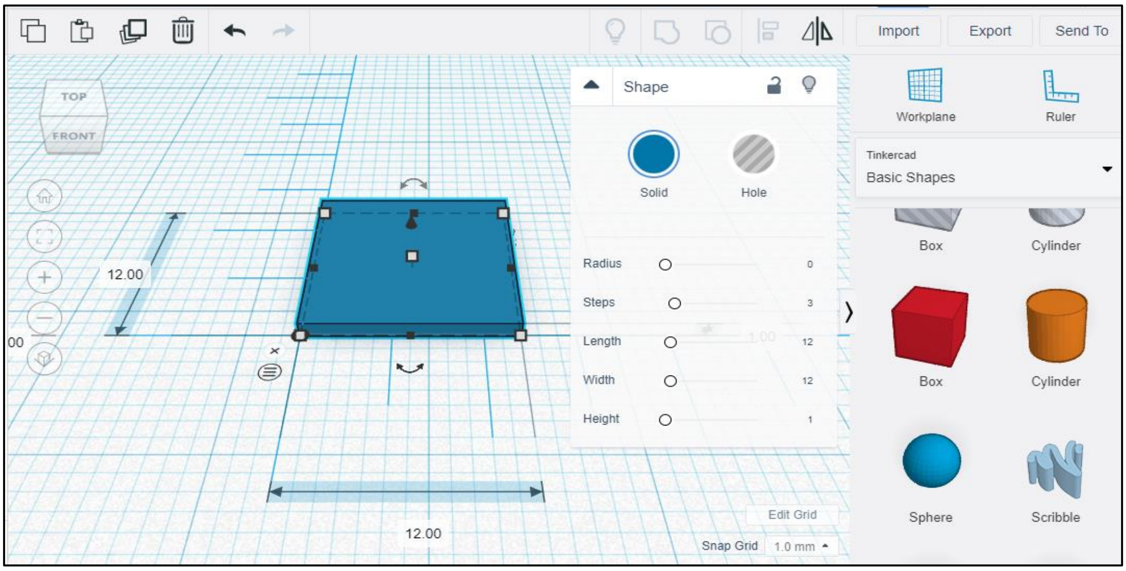

Figure 8: The measurement of the model using ruler

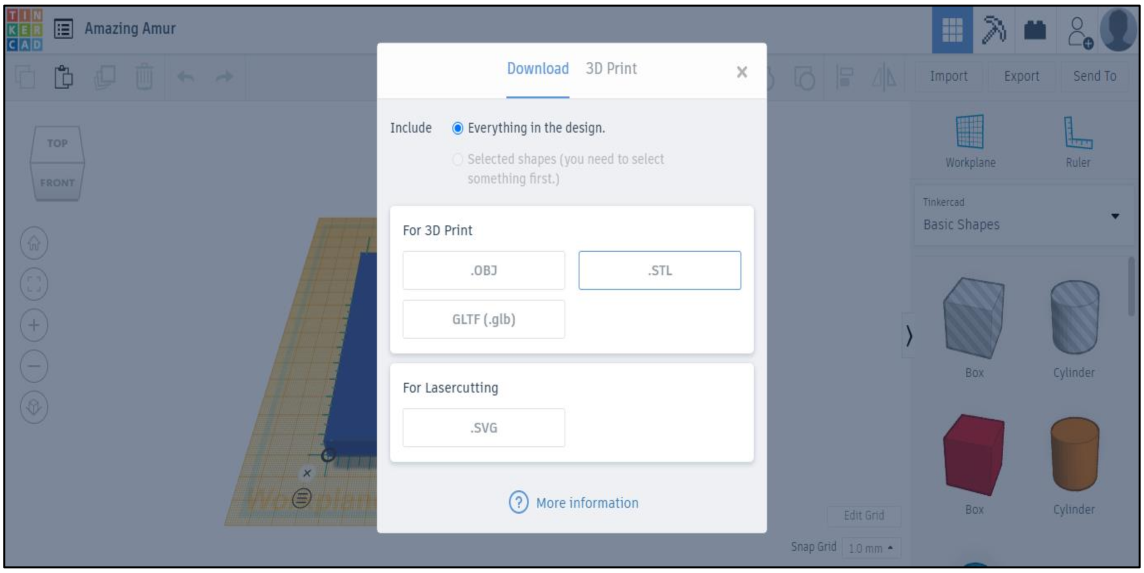

Figure 9: The OBJ, STL and GLTF 3D format files available in Thinkercad software

3.2.2 Layer slicing and parameters insertion in Cura software version 4.6.1

Once the STL file was saved, the file was exported to slicing software, Cura. The model can be viewed in x, y, and z views to ensure the position in the software. In this software, printing parameters such as extrusion temperature, printing speed, infill density, layer height, shell thickness, bottom and top thickness, filament diameter, nozzle diameter, infill pattern, and retraction are set manually in the provided parameter. In this study, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90% and 100% infill densities were set and the grid pattern was chosen as the internal geometry of infill density of PLA. Moreover, the parameters were set with 30 mm/s printing speed, 0.1 mm layer height, 200° Celsius operating temperature, and 0.15 mm nozzle diameter, without base support and no heated bed during the printing process. The parameters must be chosen carefully according to the material properties to fabricate good quality products. The grid pattern is chosen as the internal geometry of infill density of PLA.

Then, 'slice' was clicked at the bottom right of the page to start the process of slicing in order to produce the 3D model into a series of thin layers (2D). Notably, the model was viewed in top in order to observe its internal geometry after the slicing process. The slicing process was important to do before the printing as it could make the 3D printer to print out each layer of the object easier in a linear movement. After slicing, the internal geometry for each density and layer movement viewed in the preview. In this study, the layer height of 0.1mm was used to produce for a total of 99 slices of layers. The views of infill densities were taken at slice 52 as the image of infill pattern and spaces among the patterns can be visualized clearly. Figures 10, 11, 12, and 13 explain the position of 3D model from the x-direction in Cura software, The position of 3D model from the y-direction in Cura software, internal geometry with infill density after slicing and the layer slicing in a 45° linear movement.

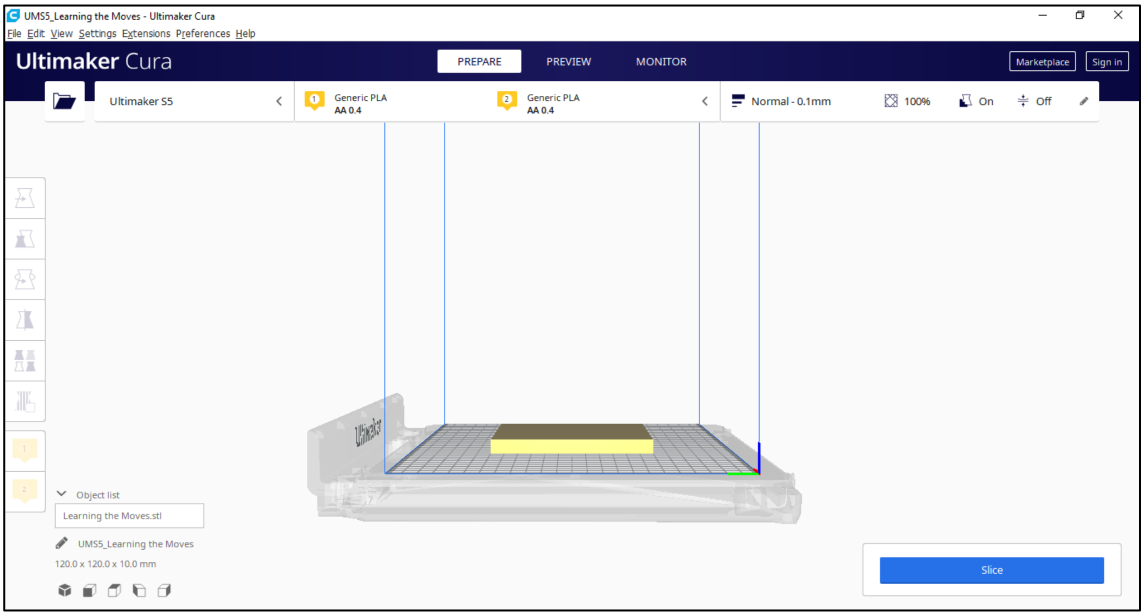

Figure 10: The position of 3D model from the x-direction in Cura software

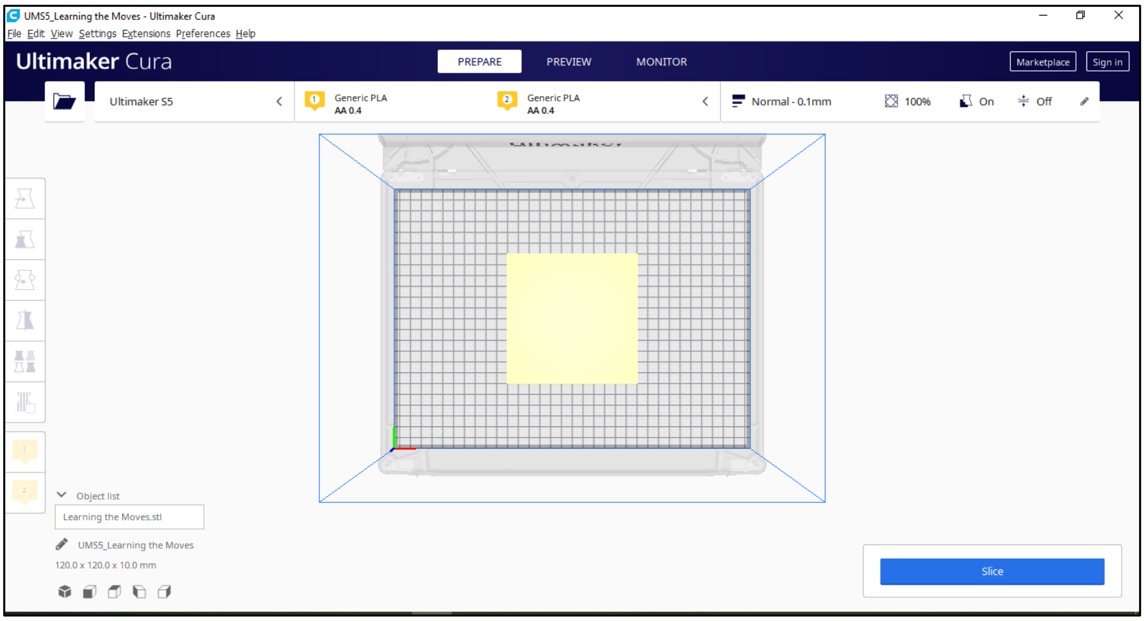

Figure 11: The position of 3D model from the y-direction in Cura software

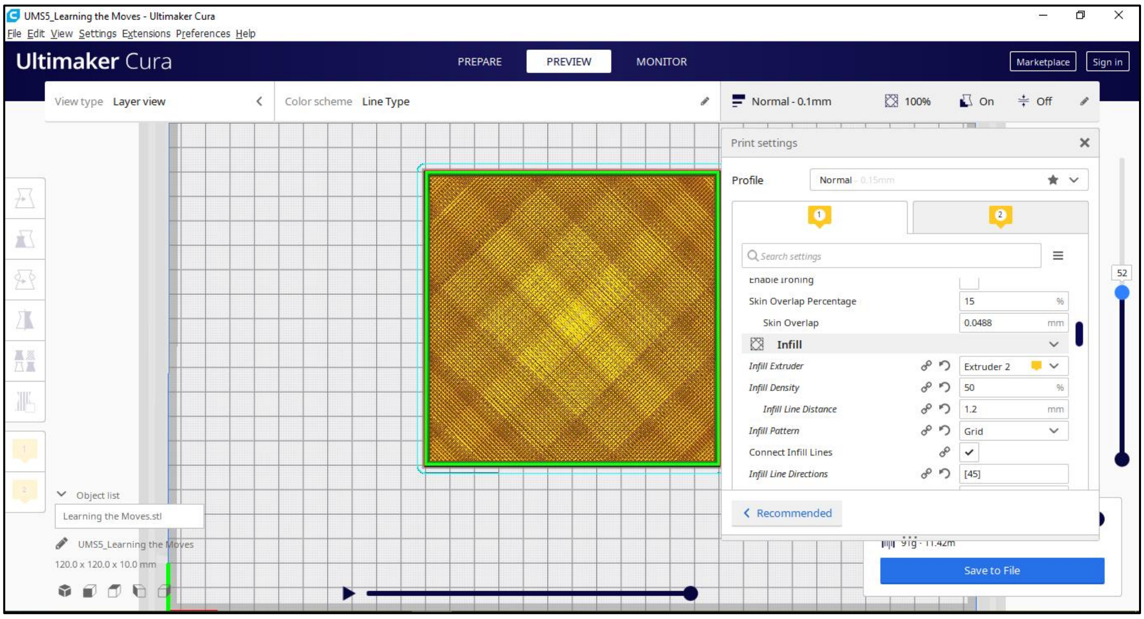

Figure 12: The internal geometry with infill density after slicing

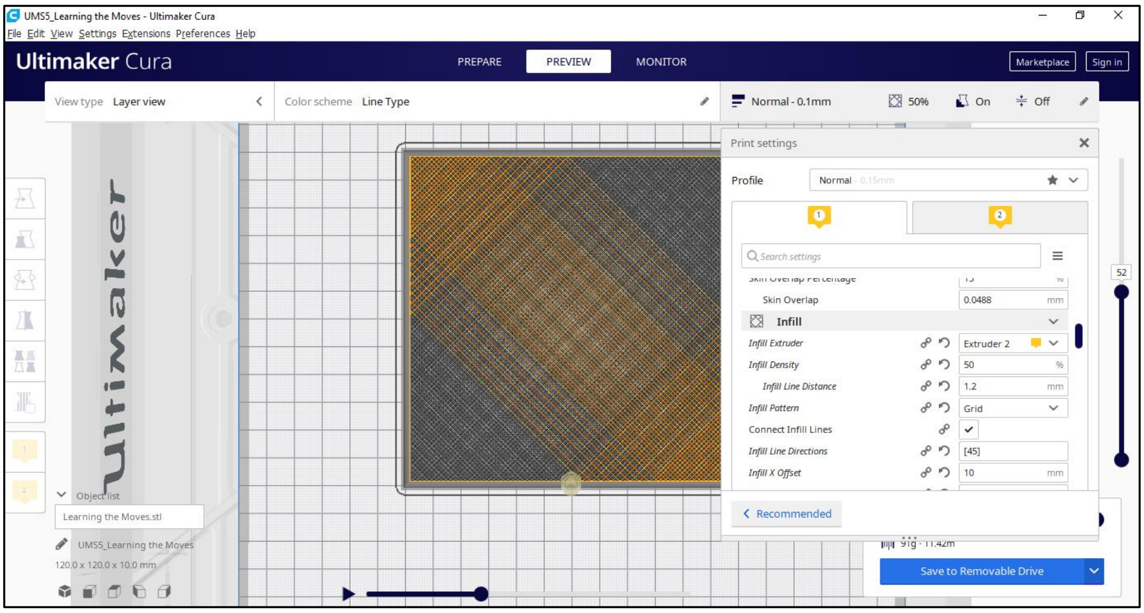

Figure 13: Shows the layer slicing in a 45° linear movement

3.2.3 Fused Deposition Modelling (FDM) process printing

The 3D printing of the PLA material with infill density of 30% was printed using MyVista Cube 200 printer. Technically, the printing process of the PLA filament was pulled by a pair of rollers through the extrusion nozzle and was heated to its melting poiny (200℃) in the nozzle. The nozzle was controlled by translated coordinate (x, y, z) in the computer to produce the dimension of the model. The PLA filament object was printed by layers from bottom to top and harden immediately as each layer stacked together to another.

Theoretically, the printing process takes about several minutes for each phantom to complete depending on the infill density set before printing. Higher infill density takes longer time for the printing process to complete. Besides, FDM printer commonly used in the manufacturing of plastic material because it was cheap, user friendly, and easy for accessibility. Besides, this technology was suitable to use with PLA material to build a model as it can endure heat, chemicals, and mechanical stress. Figures 14 and 15 show the schematic image of the FDM 3D printing process and the flow steps of the 3D printing process.

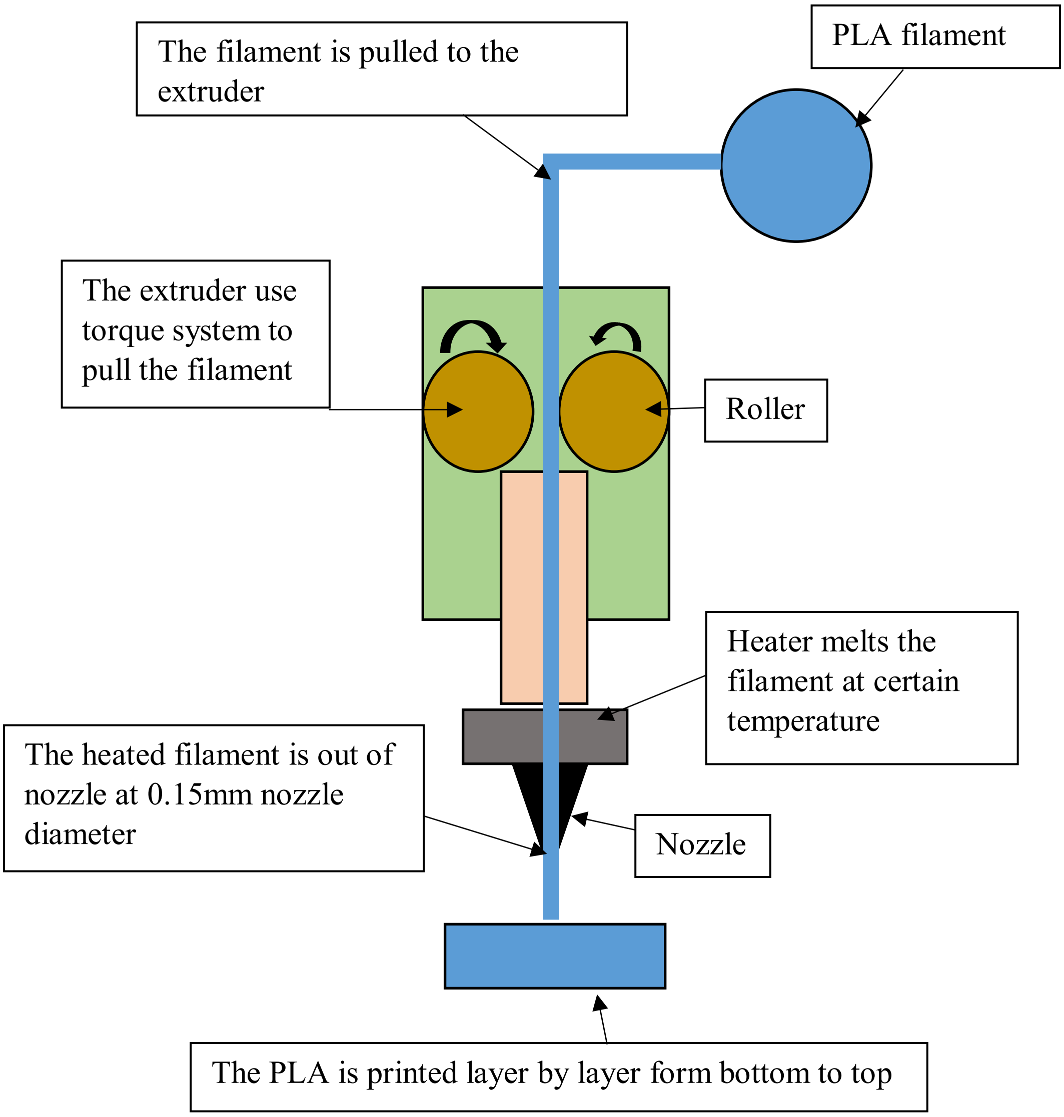

Figure 14: The process of the FDM 3D printing technology