THE EFFECTS OF PRINTING PARAMETERS ON THE TENSILE PROPERTIES OF 3D PRINTED THERMOPLASTIC POLYURETHANE (TPU) VIA FUSED DEPOSITION MODELING (FDM) METHOD

EMIELLIA POUL DAWAS

UNIVERSITI SAINS MALAYSIA

2022

SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

THE EFFECTS OF PRINTING PARAMETERS ON THE TENSILE PROPERTIES OF 3D PRINTED THERMOPLASTIC POLYURETHANE (TPU) VIA FUSED DEPOSITION MODELING (FDM) METHOD

By

EMIELLIA POUL DAWAS

Supervisor: DR. SHAH RIZAL KASIM

Dissertation submitted in partial fulfillment of the requirements for the degree of

Bachelor of Engineering with Honours

(Materials Engineering)

Universiti Sains Malaysia

August 2022

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'The Effects Of Printing Parameters On The Tensile Properties Of 3D Printed Thermoplastic Polyurethane (TPU) Via Fused Deposition Modeling (FDM) Method'. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

Name of Student:	Emiellia Poul Dawas	Signature:
Date:	18/8/2022	

Witness by

Supervisor:	Dr. Shah Rizal Kasim	Signature:
Date:	19/8/2022	

ACKNOWLEDGEMENT

First and foremost, it gives me immense pleasure to thank our school dean, Profesor Ir. Dr. Mariatti Jaafar. Also, my heartfelt gratitude and appreciation go to my supervisor, Dr. Shah Rizal Kasim, who has assisted me in improving my thesis and providing constructive advice while completing my final year project. Without his knowledge and encouragement, this effort would not have been possible.

I am grateful to my co-supervisor, Dr. Syazana Ahmad Zubir, for her guidance with the data interpretation, which significantly benefited the research process. I am indeed grateful and beholden to her for sharing her experience, as well as her genuine and valuable comments and support that was extended to me.

I'd want to take this opportunity to thank all of the lecturers, laboratory, and workshop (bengkel) technicians for their assistance and support during this whole time. I also want to thank my parents and family members, as well as my classmates and peers, for their ongoing motivation, support, and care. Furthermore, I'd like to thank the postgraduate students who contributed ideas and knowledge that substantially aided the research work.

I also place in the record, my sense of gratitude to everyone who has helped with this project, directly or indirectly. With all their support and motivation, I was able to complete my final year project in 2022.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

3D	3 Dimension
AM	Additive Manufacturing
ASTM	American Society for Testing
CAD	Computer-aided design
DLP	Digital liquid processing
DOD	Drop-on-demand
DSC	Differential scanning calorimetry
Eb	Elongation at break
FDM	Fused deposition modeling
FFF	Fused filament fabrication
FTIR	Fourier transform infrared spectroscopy
LOM	Laminating object manufacturing
MFI	Melt flow index
SEM	Scanning electron microscopy
SLA	stereolithography
SLS	Selective laser sintering
STL	Standard triangle language
OM	Optical Microscopy
TPU	Thermoplastic polyurethane
UV	ultraviolet

LIST OF SYMBOLS

%	Percent
°C	Degree Celsius
g/cm^3	Gram per cubic meter
mm/s	Millimetre per second
MPa	Mega pascal
Tm	Melting temperature
Tg	Glass transition temperature

THE EFFECTS OF PRINTING PARAMETERS ON THE TENSILE PROPERTIES OF 3D PRINTED THERMOPLASTIC POLYURETHANE (TPU) VIA FUSED DEPOSITION MODELING (FDM) METHOD

ABSTRACT

In this research work, the primary purpose is to obtain an optimized printing parameters for the 3D printed thermoplastic polyurethane (TPU) using the fused deposition modeling (FDM) process to have non-defective parts and achieve higher tensile strength that is suitable for biomedical applications. The 3D printing parameters studied in this research were the printing speed (35 mm/s, 50 mm/s) and infill density (30%, 65%, 100%). The raw materials used for the FDM method are TPU filaments with two different shore hardness (72D and 98A). Different shore hardness of TPU was used to investigate how different hardness will affect the tensile strength. The thermal properties, rheological behaviour and its chemical composition were analyzed via differential scanning calorimetry (DSC), melt flow index (MFI), and Fourier transform infrared spectroscopy (FTIR) for the filaments. DSC analysis was set in the temperature range of 25 - 280 °C and it was used to study the melting temperature and crystallization of TPU 72D and 98A. The glass transition temperature (Tg) and exothermic peaks for both TPU filaments were not present as TPUs Tg temperature is shifted to much lower temperature and no cooling steps are being conducted. MFI test was used to evaluate the flow rate of the thermoplastic filaments and the results showed that 98A has higher MFI than 72D. A higher MFI contributes to lower viscosity, whereas lower MFI corresponds to a larger molecular weight. The physical and mechanical properties were evaluated via optical microscope (OM), scanning electron microscopy (SEM), tensile test, and density test of the 3D printed dumbbell shape of 72D and 98A. The density test data showed that in overall, 72D

samples exhibit the highest density compared to 98A since 72D has more hard segments (HS) count present in its structure compared to 98A. Tensile test data showed that TPU 98A exhibited higher tensile strength and elongation at break compared to 72D but lower in terms of the tensile modulus. Hence, the non-defective part and higher tensile strength of 3D printed TPU 98A had achieved the desired mechanical properties, as the result parameters at 35 mm/s of printing speed and 65% of infill density showed the best parameters for a 3D printer.

KESAN PARAMETER-PARAMETER PERCETAKAN TIGA DIMENSI (3D) TERHADAP SIFAT TEGANGAN PLASTIK HABA POLIURETANA (TPU) DENGAN MENGGUNAKAN KAEDAH PEMODELAN TERLAKUR PEMENDAPAN (FDM)

ABSTRAK

Objektif utama kajian ini adalah untuk mendapatkan parameter optimum bagi pencetakan tiga dimensi (3D) plastik haba poliuretana dengan menggunakan pemodelan bersatu pemendapan (FDM) bagi mendapatkan sampel bahagian sempurna tanpa kecacatan dan mempunyai sifat tegangan tinggi supaya sesuai dengan aplikasi bahan bioperubatan. Dalam kajian ini, parameter-parameter pencetakan 3D yang digunakan adalah kelajuan pencetakan (35 mm/s, 50 mm/s) serta pengisian ketumpatan (30%, 65%, dan 100%). Bahan mentah di dalam kajian ini untuk kaedah FDM adalah filamen TPU dengan dua kekerasan berbeza (TPU 72D dan 98A). Kekerasan berbeza digunakan bagi menyelidiki bagaimana kekerasan yang berbeza dapat mempengaruhi kekuatan regangan. Sifat-sifat haba, reologi serta komposisi kimia telah dianalisis melalui ujikaji pengimbasan perbezaan kalorimeter (DSC), indeks aliran lebur (MFI) serta spektroskopi infra-merah jelmaan Fourier (FTIR) telah dikendalikan untuk kedua filamen. Analisis DSC telah ditetapkan dengan julat suhu antara 25 - 280 ℃ dan suhu lebur serta penghabluran bagi 72D dan 98A telah dinilai. Suhu peralihan kaca serta puncak luah haba tidak dapat diperhatikan semasa analisis DSC kerana suhu peralihan kaca bagi TPU mempunyai suhu jauh lebih rendah dan langkah pendinginan tidak dilakukan. Tujuan ujian MFI dijalankan adalah untuk mengkaji kadar aliran filamen-filamen plastik haba and keputusan ujian bagi MFI menunjukkan bahawa 98A mempunyai nilai MFI lebih tinggi berbanding 72D, dimana nilai MFI tinggi menyumbang kepada kelikatan rendah, manakala nilai MFI rendah

berhubung kait dengan berat molekul yang besar. Sifat-sifat fizikal serta mekanikal telah dikaji melalui mikroskop optik (OM), mikroskop imbasan elektron (SEM), ujian tegangan, serta ujian ketumpatan khusus bagi sampel berbentuk dumbel dicetak secara 3D bagi 72D serta 98A. Keputusan ujian ketumpatan menunjukkan bahawa secara keseluruhan, sampel TPU 72D mempunyai ketumpatan tertinggi berbanding dengan TPU 98A kerana 72D mempunyai bilangan ruas keras (HS) banyak terdapat di dalam strukturnya. Selain itu, hasil ujian tegangan menunjukkan bahawa TPU 98A mempunyai nilai tinggi bagi kekuatan regangan serta pemanjangan ketika gagal berbanding 72D tetapi nilai bagi modulus tegangannya rendah. Oleh itu, sampel sempurna tanpa kecacatan dengan kekuatan regangan tinggi telah dicapai oleh TPU 98A yang dicetak secara 3D dengan mempunyai parameter pada kecepatan pencetakan 35 mm/s dan 65% pengisian menunjukkan bahawa parameter optimum untuk printer 3D dan telah memperoleh sifat-sifat mekanik yang diinginkan.

CHAPTER 1: INTRODUCTION

1.1 Research Background

Additive manufacturing (AM) is the modern industrial production name for 3D printing, a computer-aided technique where the process involves extruding and depositing the materials in layer-by-layer to build three-dimensional objects. This design-driven technology represents a new production technique, and its manufacturing capabilities are gradually advancing. AM is certainly outdoing the conventional method as it reduces the usage of material and time while managing and optimizing production parameters for enhanced product quality (Karar, Kumar and Chattopadhyaya, 2020). Conventional approaches are quite inefficient, and a substantial amount of material is turned to scrap after a relatively long manufacturing process.

Despite that, the quality of AM fabricated parts is influenced by a variety of machine, geometry, and process parameters. Since the heterogeneity of these characteristics has a significant impact on manufacturing, standardized processes and harmonized techniques must be established to distinguish the technology for end-use purposes and qualify the technology for manufacture (Ituarte et al., 2015). Since its initial development, 3D printing has been the perfect instrument for creating prototypes during the design process of a product, thereby reducing the time required for product development, and it has emerged as the most viable approach for speeding up prototyping in a broad range of sectors, notably the medical industry (Patrich et al., 2021).

This work proposes a methodology for improving the process parameters during the production process by investigating the influence of printing parameters on the tensile properties of 3D printed thermoplastic polyurethane (TPU) using Fused Deposition Modeling (FDM). As compared to other 3D printing methods, such as stereolithography (SLA) and selective laser sintering (SLS), FDM is more budget friendly, low complexity, easy ergonomics, filament can be reused, and a variety of material choices are available. De Laurentis and Mavroidis (2004) stated that FDM generates integrated parts with unique shapes, reducing the requirement for assembling pieces and it is also widely recognized AM technology that uses spooled polymers, such as TPU that was used in this research work. Figure 1.1 shows the schematic illustration of the FDM 3D printing technology.

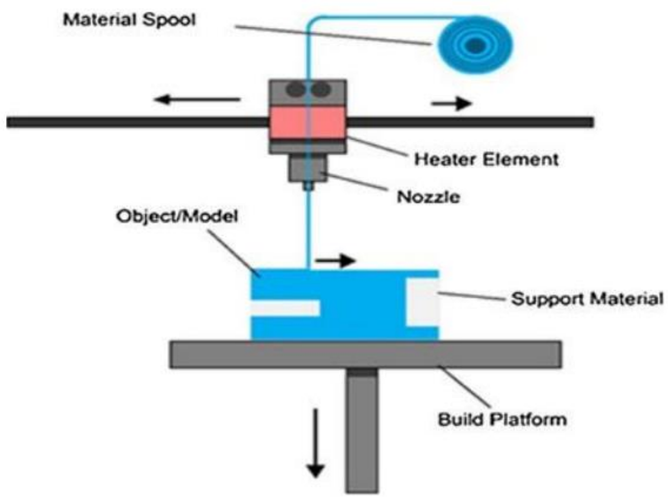

Figure 1.1 FDM 3D printing diagram (Kianoush and Liu, 2020)

Nylon (polyamide), acrylonitrile styrene acrylate (ASA), polylactic acid (PLA), TPU, thermoplastic acrylate (PMMA), and polyethylene terephthalate glycol (PETG) are the most common polymers used in product manufacturing. These materials have undergone extensive research in order to compete for qualities with metals and other conventional materials. Due to its 'on schedule' production and personalized design manufacturing capabilities, this rapid prototyping approach is broadening in the medical industry for catheter or even implant preparation (Yadav et al., 2020). Aside from that, polymers are inexpensive and hence offer a greater potential to be used in various applications, with a great emphasis on the medical community. This is because it is highly resistant to the detrimental effects of many media. Furthermore, one of the unique properties of polymers is their ability to be designed for specific demands by altering the composition of the atoms or the molecular structure that repeats. The ability to perform chemical alteration also has a massive impact (Asaad, Svitlana and Vyacheslav, 2018).

In medical terminology, a biomaterial is "any natural or synthetic material (including polymer or metal) that is designed for introduction into living tissue, particularly as part of a medical device or implant." From the viewpoint of healthcare, it can be understood as "materials that have certain unique qualities that allow them to come into direct contact with living tissue without triggering any harmful immune rejection response." (Sumrita and Ashok, 2013). Biodegradable polymers are desirable biomaterials due to their capability to break down, excreted, or are reabsorbed under all conditions. They do not need removal or surgical interventions as they are eliminated from the body after they serve their intended purposes. Biodegradable polymers should deteriorate at the same rate as the healing and regeneration processes. Mechanical qualities that are required should be obtainable. The polymer must have excellent biocompatibility with the human body over time and not cause immunological responses. Furthermore, the breakdown of the products should be harmless, quickly digested, and eliminated. The material should be simple to produce and stable enough to withstand the fabrication process (Kunduru, Basu, and Domb, 2016). Hence, that is why biodegradable polymers TPU were chosen for this research because using it will benefit the medical area as well as other industries.

3D printing has the potential to build and fabricate sophisticated biomedical devices based on computer design and patient-specific anatomical data as compared to traditional manufacturing technology, because of its distinct benefits such as freeform fabrication, sustainable and efficient manufacturing, and quicker time from design to production. 3D printing has progressively expanded from its initial application as pre-surgical visualization models and tooling molds to build one-of-a-kind devices, implants, scaffolds for stem cell differentiation, diagnostic platforms, and drug delivery systems (Chia and Wu, 2015). However, in Malaysia, the lack of acceptance of 3D printing technology by the local sector has led to a plea for the government and local practitioners to encourage the implementation of this advancement for a variety of industries, notably biomedical products (Shahrubudin et al., 2020).

The process parameters can be altered to achieve the desired quality and mechanical qualities, and the parameters will play a significant role in determining tensile strength, ductility, density, dimensional accuracy, and surface quality. Printing parameters such as printing speed, layer thickness, printing temperature, infill percentages, and surface inclination angle influence the microstructure of the printed part. These parameters also determine the machine run time and energy consumption, as well as the manufacturing cost. So, depending on the type of application, process parameters can be modified to achieve acceptable quality and economical. Dimensional accuracy is mostly affected by layer thickness and printing speed, while surface roughness is affected by surface inclination angle and layer thickness. Printing speed and layer thickness have the greatest impact on energy usage and productivity. Seemingly, layer thickness and printing speed are more important than the other parameters and usually affect the outcome of the printing process. However, in order to assure component quality and resource consumption, there will be a compromise between layer thickness and printing speed, which must be resolved in order to obtain high-quality printed parts.

As for this term, TPU has been selected as the raw material. With its strong performance features, TPU has been frequently applied in the medical device industry and it is an ideal material for utilizing in many medical uses owing to its excellent mechanical qualities, durability, and resistance to oils and chemicals. TPU is a member of the thermoplastic elastomer (TPE) family of materials, and it nearly has the same elasticity as cross-linked elastomers (rubber) while also having the benefits of being worked like a thermoplastic and recyclable. TPU also offers the medical industry an environmentally friendly replacement for polyvinyl chloride (PVC) without sacrificing its flexibility as it does not contain any plasticizers. TPU is composed of block copolymer molecules with hard and flexible segments that alternate. This material's elastomeric nature is due to the combination of flexible, elastic segments with high extensibility and low glass transition temperature, with rigid crystallizing segments with a high melting point. By modifying the rigid phase ratio, properties like hardness, strength, rigidity, extensibility, and low-temperature flexibility can be varied over a wide range.

1.2 Problem Statement

Although the manufacture of 3D printed TPU has advanced significantly in other industries over the past few decades, a proper TPU filament for FDM printing technique is still urgently needed. According to Albaiji's (2018) study, this technology is still not fully utilised by manufacturers in terms of end-use products and still has some performance issues that need to be resolved to improve conventional production processes. Repeatability capabilities is one of the issues when it comes to generating continuous runs of similar designs. One of the factors affecting the repeatable performance of manufactured parts is the printing settings.

FDM techniques could produce intricate geometrical components and are frequently utilized for quick prototyping, however, poor mechanical properties of the fabricated parts have been a great challenge that limits their medical applications. In a prior study, fused filament fabrication (FFF), which has been stated to be capable of producing high-quality products, was employed by the author Kurfess (2017). Numerous procedural issues exist, particularly regarding machine repeatability. The machine's capabilities and whether the sort of FFF machine used will have an impact on them are crucial factors in deciding how predictable the performance of the product will be. Same problem was brought up with the FDM method as well, where the type of FDM machine will influence its capacity to run and print repeatable components, wherein with time, faults on printed products will become more prominent. Additionally, Pilipovi et al. (2020) reported using Polyjet technology, which uses liquid polymers as opposed to FDM's thermoplastic filament. They concluded that since the products printed in one set are dimensionally closer to one another, it is desirable to 3D print a product every day rather than waiting a week or more between production to assure high precision and tolerance of printed parts. That is, like traditional production, most of 3D printers, including FDM, require some time to stabilise the cycle. Before using these 3D printed components in applications where accuracy is essential, more research should be done to quantify the relationships between the various qualities and the repeatability of the parts. More study are needed to specify printer variables like printing temperature and feed rate, particularly considering the lack of information on the physical characteristics of FDM's printed parts.

TPU for biomedical printing does not offer in-depth material characterisation, and little new information is being discovered. Considering this, it is viewed as a possible breakthrough and a challenge in determining the proper 3D printer parameters for the TPU's optimization in biological applications. By adjusting the printing parameters to achieve zero flaws in the TPU printed item and using two different shore hardness (72D and 98A) for comparison to study how varying hardness will impact tensile strength, the repeatability performance of the FDM machine is thus examined in this work. The dumbbell shape according to ASTM D638 (2018) type V is proposed in this work to further investigate the effect of printing parameters on the tensile strength of the TPU printed parts. To further examine the impact of printing parameters on the tensile strength of the printed parts, the ASTM D638 (2018) type V dumbbell shape is proposed. As the FDM method is a slow and time-consuming process, the dumbbell form type V was chosen for this study project, because printing a type I ASTM D638 part takes around an hour but printing a type V part only takes around ten minutes (Anand Kumar and Shivraj Narayan, 2018). ASTM D638 type V also complies with the approved tensile test procedure. The printing temperature and bed temperature were kept constant throughout the procedure, and the 3D printer's variables were printing speed and infill density. The 3D printer's parameters were created with the goal of demonstrating effective and optimal mechanical properties with zero defects in production, giving it the potential to have a significant impact on the medical sector by opening new opportunities for the creation of specialised and demanding medical applications.

1.3 Research Objectives

The primary purpose of this research was to obtain an optimized printing parameter for the 3D printed TPU using the FDM process in order to have non-defective parts and achieve higher tensile strength that is suitable for biomedical applications.

Therefore, there are three stated objectives in this research:

a. To determine the optimum printing parameters such as printing speed (35 and 50 mm/s) and infill density (30,65, and 100%).
b. To fabricate the non-defect dumbbell shape of TPU via the 3D printing method.
c. To evaluate the rheological and thermal properties of TPU filament and the physical and mechanical properties of printed dumbbell shape of TPU.

1.4 Research Approach

There are 4 stages in this study. Details for each step are explained in the subsections below.

1.4.1 Stage 1

In stage 1 the characterization of the thermoplastic filament which is TPU with two different shore hardness (72D and 98A) is provided in order to obtain the thermal properties and its rheological behavior via differential scanning calorimetry (DSC) and melt flow index (MFI) test respectively.

1.4.2 Stage 2

Stage 2 involves the 3D image development via SOLIDWORK where first the samples were designed using SOLIDWORK software, in which the dimension of the tensile test samples was followed according to ASTM D638 type V. After the drawing is completed, the model will be sliced using Ultimaker Cura 4.13.1 software to be converted to an STL file so that the 3D printer is able to read the file and print the desired products.

1.4.3 Stage 3

Stage 3 is the fabrication of the 3D printed filament via FDM method. All samples were printed with the same bed temperature (40℃) and printing temperature (225℃) while varying the printing speed (35 mm/s and 50 mm/s) and infill density (30%, 65%, and 100%).

1.4.4 Stage 4

Stage 4 is the characterization and mechanical testing of the 3D printed dumbbell shape of TPU to evaluate its physical and mechanical properties via optical microscope (OM), scanning electron microscopy (SEM), tensile test, and density test.

1.5 RESEARCH OUTLINE

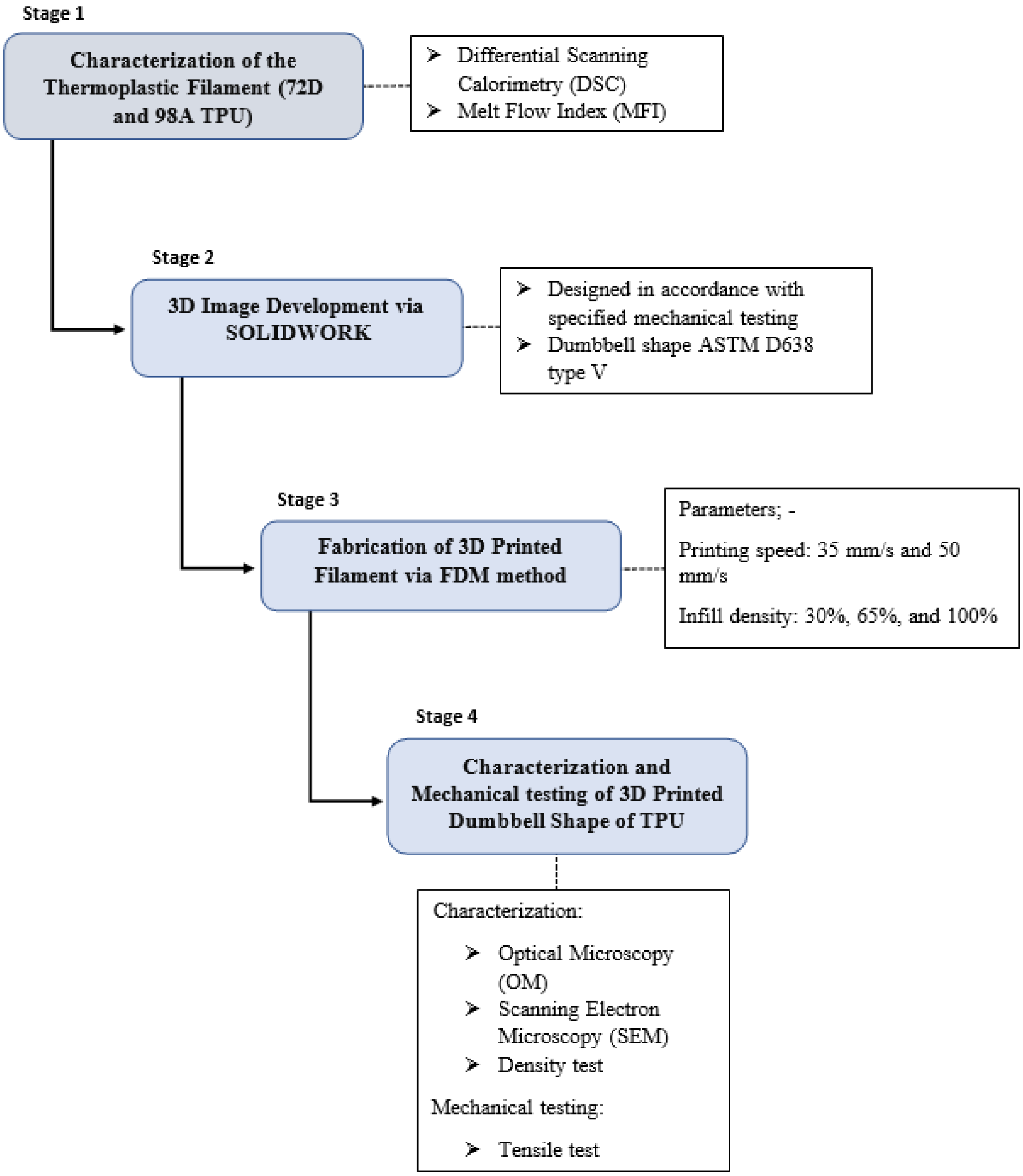

Figure 1.2: The outline of four stages that involves in this research work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to Three-Dimensional (3D) Printing Technology

Creating actual products from digital models with 3D printing or known as additive manufacturing (AM) is a revolutionary emerging technology and it has become mainstream with more people having access to 3D printing equipment and materials. In the fields of engineering, communication, and medical and biomedical sciences, this is cutting-edge technology. In addition to the creation of new materials and novel additive manufacturing processes, AM has reignited interest in business, academia, and the media. It is believed that AM can surpass conventional manufacturing methods and redefine how products are created, produced, and shipped throughout the world. In the definition of innovation policy today, technology plays a strategic role on a global level. AM is regarded as a tool that helps businesses acquire a competitive edge. Offers customers additional options for quick product and production line reconfiguration, distributed manufacturing, customization, and the development of self-engineered products (Iñigo Flores et al., 2016).

According to Omar D. and Patrick (2018), since 1984, the idea of AM has developed, making it feasible to construct 3D objects layer by layer. In 1986, a patent was issued for the use of photopolymer resin in 3D printing. The AM method has substantially evolved and refined since then. Figure 2.1 below shows the timeline of AM process. Numerous industries, including those in the automobile, aerospace, healthcare, and construction, have adopted 3D printing. The rapid development of 3D printing will continue as it seeks to become more effective and affordable. The industry is interested in lowering the cost of products, forming complicated structures out of various materials, and improving the speed and accuracy of 3D printers. The cost of distribution, assembly lines, inventory, and ultimately the product itself are all affected by these efficiencies.

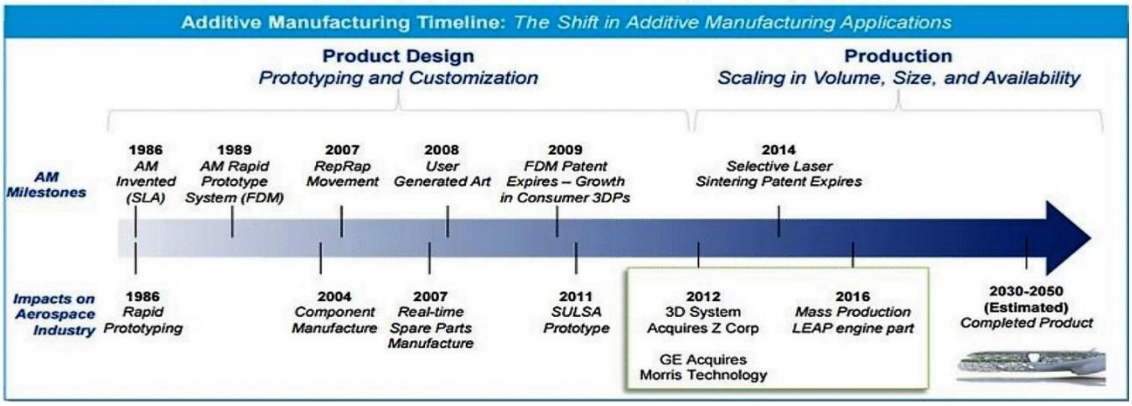

Figure 2.1: Timeline of Additive Manufacturing process (Columbus, 2015)

One of the plastic manufacturing technologies is 3D printing, in which an object is created by fusing or depositing materials to build a 3D solid. There are many different types of 3D printing techniques that vary in technologies, speed, resolution, and materials. These techniques include stereolithography (SLA), selective laser sintering (SLS), digital liquid processing (DLP), laminating object manufacturing (LOM), and fused deposition modeling (FDM), all of which use the same concept of designing the objects first and then printing them. First of all, using CAD software, for example, SolidWorks, AutoCAD, Catia, and Blender, the desired objects can be drawn in 2 dimensions, or even can be scanned by using a 3D scanner where a real-life object is scanned in order to obtain the model then it can be set to be printed. Next, the drawing file is converted into standard triangle language (STL) file format and this file will be open in the 3D printing software such as Cura, Slic3er, OctoPrint, and Simplify 3D, where the model is "sliced" into digital cross-section and transform the STL file to G-code file so that the 3D printer could use them as a guide to print (Soliman, Feibus and Baum, 2015).

Then, as stated by Ramya (2016) in his earlier study, material or a binding material may be deposited on the bed or platform depending on the machine being used. It operates by repeatedly moving the print head in the x, y, and z directions to print the material layer by layer until the desired object is completely formed. Figure 2.2 below depicts the product development using 3D printing from designation until the manufacturing process. Some 3D printing processes can incorporate various materials to create parts, and some may additionally use supports to help manufacture the part. After printing is finished, supports can be discarded or dissolved in a suitable medium to achieve the finished product. Post-processing to get good surface quality may not be necessary for some 3D-printed parts, but it may be for others. The ability of 3D printers to design and produce practically any geometric shape is its most significant benefit. Undoubtedly, 3D printing is a quick, easy, and economically viable way to directly build models from 3D CAD.

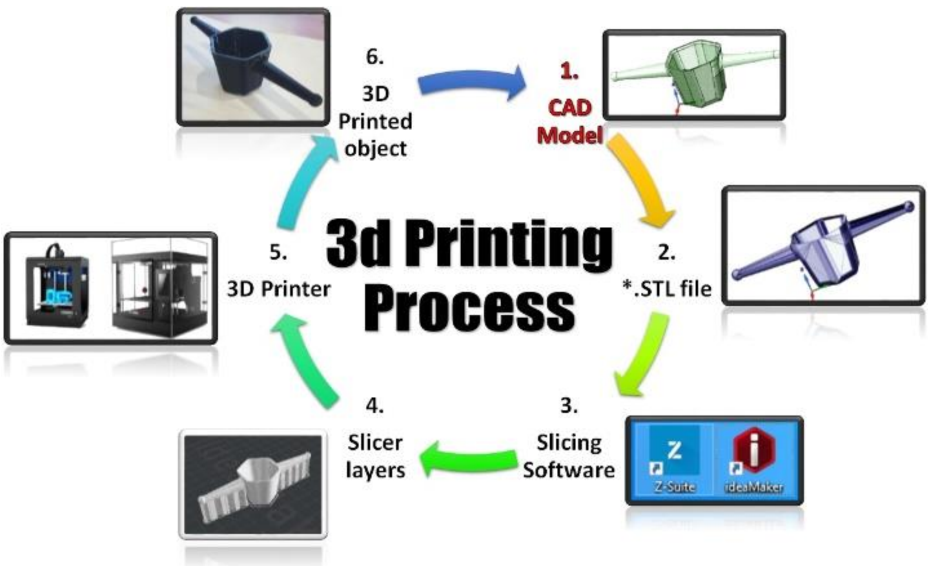

Figure 2.2: 3D printing process of the product development (recreate3d.co.za, n.d.)

2.2 The Challenges of 3D Printing Technology for Manufacturing

Even though 3D printing technology is still very much in its early stages in Malaysia, it is anticipated to grow and become a significant invention for the nation, especially in the fields of engineering, industry, the arts, education, and medicine. Only a small number of studies have concentrated on the management aspects of technology, including discussions of the difficulties and supply chain management. The vast majority of researchers have exclusively focused on engineering applications with a focus on materials, processes, techniques, and machinery used in optimization (Shahrubudin et al., 2020).

The issue in implementing 3D printing technology, according to Boetker et al. (2016), is finding appropriate materials that can meet the flow characteristics and needs for modifying the nozzle temperature and speed of 3D printing. There is a limited choice of materials especially biocompatible materials. The choice of materials for 3D printing is made based on the printing resolution, the 3D printing method, and the material specifications based on likeness and compatibility for organs and tissues. The materials must be chosen and refined in accordance with the product's intended use or application.

As reported by Pires et al. (2014), maintaining exact dimensions, particularly with regard to thickness, is difficult with 3D printing technology. It is said that flat surfaces or unsupported, long-thin features are not ideal for 3D printing and the accuracy of 3D prints depends on the product's design. Accuracy will also result in smaller part size. The issue of dimensional accuracy with FDM-based printing was also brought up by Scott (2017). However, extremely high levels of precision and resolution can be attained by employing inkjet or poly-jet models. A part's dimensional accuracy is affected by a number of variables, including the projector's firmware controls, XY resolution, screw movements of the platform's machines, and software.

Christian (2015) claims that from a management standpoint, re-educating workers to use the new technology is the challenge associated with the industry's implementation of 3D printing technology. All technicians must learn new skills in order to operate software and printers. The staff members must become acquainted with using the software and 3D printers as this will improve their skills and industry knowledge, boost their confidence, and enable them to execute tasks more quickly and effectively. As a result, they will be more equipped to adapt to changes in the future. Cost is the next obstacle to the widespread use of 3D printing technology. The use of 3D printing technology is driven by a range of cost factors, including material costs, utility costs, and maintenance costs for the equipment. The use of 3D printing also involves several related investments, including those in hardware, software, and system integration (Emelogu et al., 2016).

Gao et al. (2015) discovered that the difficulty in manufacturing a 3D product is the lack of guidelines for a fundamental design since in the traditional manufacturing system, general and specific dimensional tolerances and machining allowances based on the ISO and US standards are required for quality assurance. Due to the varying products that need to be manufactured, different materials and equipment are required. As a result, a designer must go through a process of trial and error to produce the intended outputs. Establishing industrial dimensional accuracy requirements for AM, such as the preliminary tolerance benchmark, is even more important now that expectations for AM technologies are expanding to include the delivery of finished products.

2.3 Applications of 3D Printing in Manufacturing Technology

2.3.1 Healthcare and medical industry.

The use of 3D printing technology for developing, designing, and producing new products has quickly taken off in the market. The use of 3D printing technology in the production of biomedical products, including pharmaceuticals, synthetic skin, bone cartilage, tissue, and organs, as well as in cancer research and education, is widespread (Shahrubudin, Lee and Ramlan, 2019). The use of 3D printing technology for biomedical products has a number of benefits, including;

- Similar organ failure brought on by serious issues like sickness, accidents, and congenital abnormalities can also be printed out using 3D printing technology.
- With less expense, it can mimic the skin's natural structure. Chemical, cosmetic, and medicinal products can be tested on 3D-printed skin. Therefore, testing items on animals do not need to be done. By employing a duplicate of the skin, the researcher will be able to obtain accurate results (Yan et al., 2018).
- Has the potential to speed cancer research by creating highly controlled cancer tissue models. Patients can obtain more trustworthy and accurate data by utilizing 3D printing technology (Shahrubudin et al., 2020).
- Using 3D printing technology to print drugs increases efficiency, the accuracy of dropping size and dose, reproducibility, and the ability to construct dosage forms with complex drug-release characteristics (Ventola, 2014).
- Bony voids in the cartilage or bone induced by trauma or disease can be filled up by printing new cartilage and bone. As it focuses on generating bone, maintaining it, or improving its function in situ, this treatment differs from others that involve auto-grafts and allografts (Bogue, 2013).

2.3.2 Automotive Industry

The 3D printing phenomenon has brought new possibilities to the car sector by enabling lighter and more complex constructions in a short amount of time. For instance, Local Motor produced the first electric vehicle printed in three dimensions in 2014. By producing a 3D-printed bus called OLLI, Local Motors expanded the spectrum of uses for 3D printing technology beyond just automobiles. OLLI is a 3D printed, electric, recyclable, and incredibly intelligent bus (Kirsten, 2019). As a result, using 3D printing technology in the automotive industry allows companies to experiment with different options and emphasize them early in the development process, resulting in ideal and effective automotive design. Concurrently, 3D printing technology has the potential to reduce material waste and consumption. Furthermore, 3D printing technology can reduce costs and time, allowing for quick testing of new designs (A. S. Elakkad, 2019).

2.3.3 Electric and Electronic Industry

Through embedding conductors into 3D printed devices, various 3D printing technologies have already been widely used for structural electronic devices such as active electronic materials, electrodes, and devices with mass customization and adaptive design (Lee et al., 2017). The FDM technique used in the production of the 3D electrode provides a low-cost and time-efficient approach to mass-producing electrode materials. In comparison to commercial electrodes such as aluminium, copper, and carbon electrodes, the 3D electrode's design and surface area can be easily customized to suit a specific application (Foo et al., 2018).

Furthermore, active electronic components are any electronic devices or components that are capable of amplifying and controlling the flow of electric charges. Furthermore, active devices encompass those that produce power. Due to their complex features, these components typically require more elaborate fabrication processes than passive components. 3D printing technology offers advantages for product processing as well as electronic processing. The efficiency of an electronic system may have increased with multi-material printing technology, allowing for more innovative designs to be created in a single process. To address environmental pollution in today's society, the development of a green electronic device with low manufacturing costs, good safety, high reliability, and rapid production is needed immediately (Saengchairat, Tran, and Chua, 2016).

2.4 Types of 3D Printing

Various 3D printing technologies with different functionalities have been established. According to ASTM Standard F2792 (ASTM F2792-12a, 2012), ASTM classified 3D printing technologies into eight categories, which are as follows:

2.4.1 Material extrusion

3D printing technology based on material extrusion can be used to print multi-material and multi-color printing of plastics, food, or living cells. This method has a very low cost and is widely used. Furthermore, this process can create fully functional parts. The first example of a material extrusion system is FDM, which uses polymer as the primary material. By heating the thermoplastic filament to a semi-liquid state then extruding it and depositing it along the extrusion path, FDM builds parts layer by layer from the bottom to the top (Yap et al., 2017).

2.4.2 Material jetting

Material jetting is a 3D printing technique in which build material is selectively deposited drop by drop. A printhead dispenses droplets of a photosensitive material, which solidifies and builds a part layer by layer under ultraviolet (UV) light. Material jetting produces parts with exceptionally smooth surfaces and high dimensional accuracy. Material jetting offers multi-material printing as well as a diverse range of materials such as polymers, ceramics, composites, biologicals, and hybrids. Material jetting can be divided into three categories: drop-on-demand (DOD), nanoparticle jetting (NPJ), and polyjet technology (Engineering Product Design, n.d.).

2.4.3 Binder jetting

Binder jetting is a rapid prototyping and 3D printing technique in which a liquid binding agent is selectively deposited to join powder particles. Binder jetting technology forms the layer by spraying a chemical binder onto the spread powder. Binder jetting would be used to produce casting patterns, raw sintered products, or large-volume products from the sand. Metals, sands, polymers, hybrids, and ceramics can all be printed using binder jetting. Some materials, such as sand, did not require any additional processing. Furthermore, because powder particles are glued together, the binder jetting process is simple, quick, and inexpensive. Finally, binder jetting can print extremely large products (Low et al., 2017).

2.4.4 Sheet lamination

Sheet lamination is a 3D printing process that bonds sheets of material together to create a part of an object. LOM and ultrasound additive manufacturing (UAM) are two examples of 3D printing technologies that use this process. Sheet lamination can do full-color prints, it is relatively inexpensive, material handling is simple, and excess material can be recycled. LOM is capable of producing complex geometrical parts at a lower cost of fabrication and in less time. UAM is a cutting-edge process technology that uses sound to combine layers of metal extracted from featureless foil stock (Zhang and Liou, 2021).

2.4.5 Vat Photopolymerisation

In general, vat photopolymerization refers to the curing of photo-reactive polymers with a laser, light, or UV. SLA and DLP are two examples of photopolymerization-based (Low et al., 2017). The photoinitiator and irradiate exposure-specific conditions, as well as any dyes, pigments, or other added UV absorbers, all had an effect on SLA. DLP, on the other hand, uses photopolymers in a manner similar to that of SLA. The main distinction is the light source, with DLP employing a more traditional light source, such as an arc lamp with a liquid crystal display panel. It can cover the entire surface of a vat of photopolymer resin in a single pass, making it faster than SLA. The time of exposure, wavelength and amount of power supply are all important parameters in Vat Photopolymerization. The materials used initially are liquid, and when exposed to ultraviolet light, the liquid hardens. With fine details and a high-quality surface, photopolymerization is best suited for producing high-end products (Muller and Karevska, 2016).

2.4.6 Powder bed fusion

The powder bed fusion printing technique includes electron beam melting (EBM), SLS, and selective heat sintering (SHS). This method melts or fuses the material powder together using an electron beam or a laser. Metals, ceramics, polymers, composites, and hybrids are some of the materials used in this process. SLS is functionally fast, accurate, and has a variable surface finish. SLS is capable of producing metal, plastic, and ceramic objects, and it employs a high-powered laser to sinter polymer powders to produce a 3D product. Meanwhile, SHS