

INVESTIGATION OF DIMENSIONAL ACCURACY OF ADDITIVE MANUFACTURED SAMPLE

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)



FACULTY OF MANUFACTURING ENGINEERING

2023

DECLARATION

I declare that this project entitled "Investigation of Dimensional Accuracy of Additive Manufactured Sample" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature Mohamad Afiq Bin Sharum Name : 25th February 2023 Date : **TEKNIKAL MALAYSIA MELAKA** UNIVERSITI

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.) I hereby declare that I have read this report and in my opinion this thesis is sufficient in the terms of scope and quality.

Signature Associate Prof. Ir. Ts. Dr. Shajahan bin Maidin Supervisor Name 25th February 2023 Date TEKNIKAL MALAYSIA MELAKA UNIVERSITI

ABSTRAK

Percetakan 3D adalah suatu process dimana bahan akan dibekukan dan dicantumkan bagi membentuk objek 3 dimensi yang kompleks melalui kawalan daripada komputer. Pencetakan 3D ini digunakan dalam penghasilan prototaip dan pembuatan tambahan. Teknik yang sering kali digunakan untuk pencentakan 3D adalah teknik Pemodelan Pemendapan Berfungsi (FDM). Ketahanan bahan yang digunakan dalam FDM, kestabilan sifat mekanik mereka dalam jangka masa yang tertentu, dan juga kualiti yang baik merupakan antara kelebihan menggunakan FDM. Walaubagaimanapun, terdapat beberapa kekurangan FDM seperti penampakan garisan di antara lapisan dan juga pembentukan lebihan bahan percetakan di atas permukaan produk. Kekangan ini akan menjejaskan ketepatan demensi daripada model yang dihasilkan oleh pencetak 3D. Kajian ini telah dijalankan bagi mengenal pasti kesan-kesan dan hasil penggunaan filamen besi terhadap ketepatan dimensi produk yang dihasilkan menggunakan pencetak 3D.Perisian yang digunakan bagi membuat model kajian ini adalah dengan menggunakan CATIA dan pencetak Ultimaker 3D printer. Filamen besi, PLA Teguh dan ABS yang akan digunakan dalam kajian ini akan diuji meggunakan Coordinate Measuring Machine (CMM). Antara geometri yang telah diuji dengan CMM adalah, ketebalan, sudut jejari, sudut, diameter lubang and juga kerataan. Hasil kajian emnunjukkan bahawa tiada filamen yang mencapai 100 peratus keputusan akurasi geometri yang perlu dicapai. Kajian telah mendapati bahawa beberapa faktor telah dikenalpasti yang menjadi penyebab kepada kekurangan akurasi geometri seperti pengecilan dan kolpeks geometri ayng digunakan di dalam eksperimen. Keputusan daripada CMM. Ketetapanoptimum yang dikenalpasti boleh digunakan bagi menghasilakan produk pencetakan 3D yang mempunyai ketepatan dimensi yang lebih baik.

ABSTRACT

3D printing is a process of which material is solidified and joined to form a complex threedimensional object under the control of a computer. 3D printing is used in both rapid prototyping and additive manufacturing. The most common technique used for 3D printing is the Fused Deposition Modeling (FDM). The durability of the materials FDM used, the stability of their mechanical properties over time, and the quality of the parts are some of the advantages of using FDM. However, it also has several limitations for instance the appearance of seam line between layer and the formation of excess material residue on the parts surface. These limitations will affect the dimensional accuracy of the parts produced by the 3D printer. The test models were made using CATIA software and printed using the 3D printers. The metal filaments that will be used for this project is Stainless Steel, ABS and Tough PLA; the test models were tested using the Coordinate Measuring Machine (CMM). The thickness, corner radius, angle, perpendicularity, hole diameter and flatness are some of the geometries to be tested with the CMM. The result shows that none of the filaments are able to obtain 100% result accuracy although Stainless Steel managed to reach the closest value to the expected data. These data are then studied to identify the problems which have led to several factors such as shrinkage and geometry complexities. The optimum parameters for printed FDM sample can be used in order to achieve better dimensional accuracy for future production.

DEDICATION

This project is dedicated to

My beloved parents



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ACKNOWLEDGEMENT

In the name of Allah, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully without any predicament. I would also like to express my highest gratitude to everyone who has supported me throughout the process of completing my Final Year Project. I am very thankful for their advice throughout the process of completing this project.

First and foremost, I would like to thank my project supervisor, Associate Prof. Ir. Ts. Dr. Shajahan bin Maidin for his full support and his unwavering guidance during the whole project. Without him, this project might not be completed within time. I am also grateful for the support that I received from my also my family members, especially my parents who gave full trust and support in order to complete my studies. Last but not least, I would like to convey my thanks to my dearest friends who have been the motivation for me to keep doing better for my project and studies.

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LIST OF ABBREVIATIONS



CHAPTER 1 INTRODUCTION

1.1 Project Background

Additive manufacturing (AM) is a unique kind of manufacturing process that involves connecting materials to create products from three-dimensional (3D) model data, generally layer by layer. It offers several benefits over traditional manufacturing procedures. AM, often known as 3D printing, is a cost-effective and time-saving method for creating low-volume, customised goods with complex geometries and sophisticated material characteristics and functionality (Huang et al., 2020). In contrast to subtractive manufacturing processes, additive manufacturing (AM) is the process of connecting materials to produce items using Computer Aided Design (CAD) model data, generally layer by layer. 3D printing, additive fabrication, and freeform fabrication are all terms used to describe AM. While these new approaches are still in their infancy, they are expected to have a significant influence on production. They can provide new design freedom to the industry, reduce energy consumption, and reduce time to market.

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AM printing is undergoing a remarkable transformation, which is resulting in an exponential increase in its application. Its use grew because to its exact and repeatable design capabilities in a variety of materials. It was originally used to manufacture moulds or prototypes. This made prototyping prototypes in a variety of sizes, styles, materials, and colours much faster. The public now has access to 3D printing, and a basic fused deposition modelling (FDM) printer may be purchased at a shopping mall. Due of its simplicity, FDM technology is far less expensive than other AM approaches (Cano-Vicent et al., 2021). Fused Deposition Modelling (FDM) is a cheaper 3D printing technique mainly developed for the additively manufacturing of polymer materials. During the manufacturing process, filamentous polymer is first melted in the printing nozzle at a temperature lightly higher than the melting point of the printing polymer, then deposited onto the printer hotbed layer by layer under the control of computer, and finally fused with the bottom adjacent layers.

The dimensional accuracy of AM parts is extremely important especially in the context of manufacturing assemblies or parts that needs to precisely fit together. The studies to identify the common factors that can affect this accuracy such as raster angle, printing speed, layer thickness, and even the build orientation will be crucial in identifying the dimensional accuracy for this project. The accuracy of printed a part depends heavily on the design. Variations in cooling and curing result in internal stresses that can lead to warping or shrinkage. AM is not suited for flat surfaces or long thin unsupported features. Accuracy will also decrease as part sizes become larger while the smaller and intricate parts on this project require higher dimensional accuracy. Metals, polymers, composites, and other powders may now be used to "print" a variety of functional components, including complicated structures that can't be made any other way, using additive technology FDM has been widely employed in AM techniques that generate working prototypes in various metal printings. Steel and its alloys are the most often utilised metals in AM because of its availability, low cost, and biocompatibility as bone and dental implants. Nickel, aluminium, copper, magnesium, cobalt-chrome, and tungsten are the least often used metals, followed by titanium and its alloys. To improve mechanical qualities, crack-free metal matrix composites (MMC) with a density of 99.9% can be combined with tungsten carbide-cobalt (WC-Co), ceramic, or nonferrous reinforcements. ويوم ست

The aim of this project is to investigate the dimensional accuracy of printed 3D samples which will thus be achieved through extensive research throughout the PSM 1 and practical approach of printing and dimensional accuracy analysis during PSM 2. Specifically, in this project, Stainless Steel will be used as the main filament during the printing process. Additionally, the project will be utilizing FDM machine Ultimaker in order to print out the test samples throughout the project. The machine will be able to identify the optimum parameters in order to print the samples with ideal parameters which will then be proven by using Coordinate Measuring Machine (CMM) to identify the dimensional accuracy. The dataset that is obtained from this project will be analysed and used for further research.

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1.2 Problem Statement

One of the first AM methods is rapid prototyping. It enables the development of printed parts as well as models. The ability to generate practically any form that would be difficult to machine is one of the key benefits of this approach for product development. It saves time and money, eliminates human contact, and so shortens the product development cycle. (Wong & Hernandez, 2012). Whenever (FDM is utilised to create small intricate structures and features with extensive overhangs, FDM tends to produce unwanted faults in terms of dimensional errors (Tronvoll et al., 2018). Helical threads are often used for assembling components with fine details and significant overhangs, such as sub-millimetre scale details with 60-degree overhangs. The main performance of the additive manufacturing method determines which process parameters should be used. To assure product quality, improve dimensional accuracy, minimise unacceptable waste and substantial scraps, increase efficiency, and reduce production time and costs, production engineers must determine ideal process conditions.

Because numerous contradicting aspects impact component quality and material attributes to establish ideal parameters, the FDM process is complicated. The quality of the component and the mechanical qualities of the generated part are determined by the suitable selection of process parameters(Patel et al., 2022). In addition to the fast improvements in 3D Printing technology, this procedure has enabled the development of several unique items. However, things made using additive manufacturing may have surface roughness and dimensional accuracy concerns. Manufacturing thin-walled items, particularly those used in aviation, aerospace, and biomedicine, need a higher level of dimensional precision (Babu & Gb, 2022). Not only are build times with metal 3D printing glacially slow as compared to machining, but the pieces aren't always completed when processed, and they're not always perfectly precise. Powder bed fusion, also known as direct metal laser sintering, electron beam melting, or selective laser melting, with average tolerances of +/- 0.005 inches and a surface finish comparable to an investment casting. This results in machining is almost usually necessary to clean up any critical surfaces, bore holes, cut threads and more.

1.3 Objectives

The aim of this project is to investigate the dimensional accuracy of various open source FDM 3D printed samples.

- 1. To create CAD drawing of the test model using CATIA V5 drawing software.
- 2. To print various type of material samples sample using FDM.
- 3. To study the dimensional accuracy of the various samples printed using CMM.

1.4 Scopes of Project

The sole focus of this project is to identify the accuracy dimension and the factors that may affect the results of different samples on 3D printed samples using FDM. The samples may vary from wide ranges of shapes to measure the effectiveness of FDM as a whole. Different geometrical shapes will be highlighted throughout the project in order to measure the dimensional accuracy and project its result parallel to the different settings and settings on the machine and surrounding environment. The main software that will be used to run this project will be CATIA as the software caters to the aspects of this project. The measurements for the samples that will be printed is 1.5 cm x 1.5 cm. The metals that will be used in the printer's filament will be different each time in order to get the best readings in terms of accuracy. To obtain information on its output, the FDM prototype is physically and mechanically tested. Quality management or validation can be destructive or non-destructive in nature (NDT). Relying on the required confidence and uniqueness of the items, NDT tests may be performed on an allocated element or all components obtained. The main factors that will be considered in the research will be microstructure, hardness, tensile strength relative density and shrinkage.

1.5 Report Organization

This report consists of five main chapters and several sub-chapters namely introduction, literature review, methodology, result and discussion and finally the conclusion and recommendation. For the first chapter, it will briefly explain regarding the background, objectives, scopes, and also the importance of study which will provide readers with a better overview of the whole report.

The second chapter will focus more on the literature review on previous related research on this subject. This includes the definition and types of AM, the advantages and disadvantages of each examples of FDM. This chapter will also elaborate more on FDM and also the application of FDM.

Chapter three's main concern is about the methodology. The methodology focuses on the method or steps used in order to carry out this research. It will show how this experiment will be conducted, the experiment setup, testing technique and how to analyze of each of the data obtained from each sample. On the other hand, chapter four will display the results along with the necessary comparison including a comprehensive discussion. Chapter five will conclude the overall findings of this research and provide some suggestions for future studies.

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CHAPTER 2 LITERATURE REVIEW

This chapter will discuss some of the related knowledge on the additive manufacturing as well as the Dimensional accuracy of additive manufactured sample. Some process parameters of 3D printing are also discussed in this chapter.

2.1 Definition of AM process

Additive manufacturing processes take the information from a computer-aided design (CAD) file that is later converted to a stereolithography (STL) file. In this process, the drawing made in the CAD software is approximated by triangles and sliced containing the information of each layer that is going to be printed. There is a discussion of the relevant additive manufacturing processes and their applications. The aerospace industry employs them because of the possibility of manufacturing lighter structures to reduce weight. Additive manufacturing is transforming the practice of medicine and making work easier for architects (Wong & Hernandez, 2012).

Metal Additive manufacturing techniques is employed to manufacture the complex geometries product from 3D CAD model data. The metal powders are applied as successive layers of materials until it becomes a final product. Process parameters of the additive manufacturing include layer thickness, scan speed, hatch spacing, size of the powder particles and orientation of the layer. This AM technique is being used in various industries like biomedical and aircraft industries as this AM technique possess benefits like minimum of waste and flexibility in the design of complex shape. 3D printing of new/novel metals is being developed and need to investigate the impact process factors of 3D printed novel metals. Additive manufacturing adequately changed old manufacturing technique and it has gained great potential to fabricate the metal parts with good integrity and AM seems to be a powerful tool to minimize the complexity and able to make tailor-made products (Nurhudan et al., 2021).

As its name indicates, AM comprehends all processes that adds material during a part manufacturing, making it difficult to enumerate all of them. In this work, only the processes related to material layer addition - Layer Manufacturing (LM) are considered and are following described. The reason for this is that all LM processes considers few basic steps (Hyndhavi et al., 2018).

- 1. Material is fused, sintered or bound over a support surface depending on the process type. The material can be already laying in the surface (powder or liquid) or can be projected over it (powder, binder, extrusion), mainly by a beam fashion way and then hatched over the surface following an external contour defined by part's horizontal slice, or layer, geometry.
- 2. After the first layer is ready, the support surface is lowered by a device at a distance equal to the layer thickness and the material deposition follows the same procedure of the preceding layer, including the support surface lowering.

3. When the last layer is ready, the process is finished and the part is removed from machine compartment.

4. Depending on the process and other requirements, a post processing is performed before part delivery.



Figure 2.1: AM Deposition process (Hyndhavi et al., 2018)

2.2 General AM Process

The process of converting a virtual CAD model into a real product or prototype is known as AM. The functioning premise of AM has seven main phases. The processes can be referred in Figure 2.2



Figure 2.2: Steps in AM processes

(Source: https://additivemanufacturingindia.blogspot.com/2018/04/additive-manufacturingoverview.html)

STEP 1: CAD model design model generation

The initial stage in every product design is to imagine the product's purpose and look. Models are conceptualised using 3D digital CAD software throughout the AM process. Solidworks, AutoCAD, CATIA, and other CAD applications are examples. However, in this project, CATIA will be used as the CAD programme. An example of the CAD design in CATIA can be referred in the Figure 2.3.



Figure 2.3: Example of CAD drawing (Source: https://grabcad.com/library/lathe-tail-stock-5)

STEP 2: Converting CAD model into STL file

Almost every AM technology uses the STL file format. The STL format uses triangles to mimic the surface of a solid object. These properties enable AM pre-processing tools to determine the spatial positions of the model's surfaces. Figure 2.4 shows an example of STL file being used for CAD purposes.



Figure 2.4: STL model of a bone

(Source : https://www.researchgate.net/figure/Conversions-of-the-stl-file-into-ANSYS-format-in-CATIA-V5 fig3 339776311)

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STEP 3: STL slicing

The information that were carried out in sliced forms by the STL file will be identified by the AM machine and the product will be formed layer by layer

STEP 4: Machine Set-up

Machine preparation is required prior to beginning any printing. Before starting printing, the desired settings such as layer thickness, surface roughness, bed temperature, and printing orientation must be established.

STEP 5: 3D printing process

The printing process will be automated, and the design process will begin layer by layer. Despite the fact that the procedure takes a long time to complete, the operator/user is not required to supervise it. However, it's a good idea to keep a check on the printing process from time to time in order to avoid any unforeseen problems. The physical process of 3D printing manufacturing can be referred in Figure 2.5.



Figure 2.5: Portrayal of 3D printing process (Source< <u>https://www.safetyandhealthmagazine.com/articles/18295-d-printing-and-worker-safety</u>)

STEP 6: Removal process

Printed samples have to be removed from the machine. The standard safety procedure when removing the part is to wear a glove to protect the operators from hot samples, toxic parts or small cuts. The portrayal of the process can be referred in Figure 2.6.



Figure 2.5: Part Removal

(Source< https://www.3dhubs.com/knowledge-base/supports-3d-printing-technology-



The support structures must be removed carefully from the printed samples. Some 3D printed objects require post-processing, such as brushing off any powder or bathing the printed samples to remove water soluble supports.

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2.3 Types of AM system

2.3.1 Fused Deposition Modelling

FDM is a well-established additive manufacturing technology that is mostly used to create functioning prototypes, hence decreasing lead time, and in certain cases, end-use goods. As a result, it is necessary to thoroughly examine and construct a part with the best possible surface quality. In FDM, the planned CAD model is translated to STL (Stereolithography) file format and sliced layer-by-layer using slicing software and the FDM printer. In the print head, the material filament is semi-melted before being extruded onto the build platform(Reddy et al., 2018). The FDM technique and set up is shown in Figure 2.7.



Figure 2.7: FDM infographic (Source<<u>https://www.researchgate.net/figure/Schematic-of-fused-deposition-modelling-FDM-</u> process_fig1_324049307)

The most frequent materials utilised in the FDM method are thermoplastics such as ABS and PLA. When compared to other polymer-based AM processes, FDM parts are among the most durable. The material is extruded from the nozzle head, layer by layer, creating the component. Prior to printing, the nozzle is heated to melt the plastic. The FDM machine contains a mechanism that allows you to regulate the flow of molten plastic. The extruded polymer is placed down as the liquefier advances, first with the perimeter of the object and then filling it in. The nozzle is mounted to a mechanical stage which can be moved in both horizontal

and vertical directions. Instead of doing it according to the norm, some manufacturers used an opposite approach and move the table(Carneiro et al., 2015).

AM technologies have been successfully applied in various applications. FDM, one of the most popular AM techniques and the most widely used method for fabricating thermoplastic parts which are mainly used as rapid prototypes for functional testing with advantages of low cost, minimal wastage, and ease of material change. Due to the intrinsically limited mechanical properties of pure thermoplastic materials, there is a critical need to improve mechanical properties for FDM-fabricated pure thermoplastic parts. One of the possible methods is adding reinforced materials (such as carbon fibers) into plastic materials to form thermoplastic matrix carbon fiber reinforced plastic (CFRP) composites those could be directly used in the actual application areas, such as aerospace, automotive, and wind energy (Ning et al., 2015).

The increasing number of new developments and applications achieved by FDM in recent years demonstrates the great potential of this AM technology. During the COVID-19 pandemic, FDM was used as an alternative production method to produce personal protective equipment (PPE) such as face masks and respirator face shields. A significant number of new types of materials designed for FDM have been developed between 2020 and 2021 including new fibre-reinforced composites with superior mechanical properties, advanced polymer-based nanocomposites prepared with the addition of carbon nanomaterials and many other types of polymer-based composites with enhanced physical properties (Cano-Vicent et al., 2021).



Figure 2.8: FDM manufactured part (Source< <u>https://www.stratasysdirect.com/technologies/fused-deposition-modeling</u>)

2.3.1.1 Advantages of FDM

The main advantages of this process are that no chemical post-processing required, no resins to cure, less expensive machine, and materials resulting in a more cost-effective process. that FDM has short built time for thin wall parts and able to use different material or color in same object or layer. FDM is one of the most widely used 3D printing technologies because of its reliability and the simplicity of its process. FDM requires only a heating process to extrude the materials. Furthermore, FDM 3D printers have competitive prices when compared to other 3D printing machines(Carneiro et al., 2015). Because of the FDM printer's unique architecture, it may make gantry rails longer and therefore increase the build area. This system allows the designer to effortlessly scale any print to his specifications. The cost-to-size ratio is an additional benefit for FDM printer users. The FDM model is rather inexpensive when compared to other 3D printing. In fact, more costly 3D printers have a difficult time competing with the FDM printers on the market. An FDM printer typically costs between \$250 and \$10,000, depending on the maker and features.

2.3.1.2 Disadvantages of FDM

Despite the fact that FDM was established more than 20 years ago and its numerous benefits, it still has a number of drawbacks. The main limitation of FDM is that it can only handle polymer-based materials at the moment. Another disadvantage of FDM is its slow printing speed, which leads in a low rate of print sample generation when compared to other AM processes. The material qualities of 3D printed objects utilising FDM, like those of other AM processes, are dependent on the printing circumstances (e.g., speed, power, temperature, process). The accuracy of FDM prints is determined by a variety of elements, including nozzle diameter, filament material qualities, and processing settings. As a result, processing parameters during the printing process impact the accuracy of 3D printed components because they can alter shrinkage, bonding, and warping during cooling, which affects part assembly. Another element to consider when utilising FDM is the necessity for extensive post-processing to get the printed pieces to the appropriate surface quality. Because of the fixed nozzle and feed diameter, layer-by-layer patterns of a predefined thickness are created, which might hide tiny details in the component depending on their dimension(Cano-Vicent et al., 2021).

2.3.2 Stereolithography (SLA)

Like most solid freeform fabrication techniques, stereolithography is an additive fabrication process that allows the fabrication of parts from a computer-aided design (CAD) file. The designed external and internal (pore) geometry of the structure that is to be built can either be devised using 3D drawing computer software, be described using mathematical equations. Because stereolithography (SLA), created by 3D Systems, Inc., was the first and most commonly used fast prototyping method, the two names were formerly used interchangeably. In the late 1980s, SLA was launched as a solid freeform approach (SFF). Despite the fact that various other SFF approaches have since been created, SLA remains one of the most formidable and adaptable. (Melchels et al., 2010). SLA is a liquid-based method that involves curing or solidifying a photosensitive polymer when it comes into contact with an ultraviolet laser. The procedure begins with a model created in CAD software, which is then converted to an STL file in which the elements are "cut in slices" and each layer's information is stored. The equipment utilised determines the thickness of each layer as well as the resolution. To attach the component and support the overhanging structures, a platform is constructed. The UV laser is then used to harden particular spots of each layer on the resin(Wong & Hernandez, 2012).

The curing reaction of resins, which is an exothermic polymerization process defined by chemical cross-linking reactions, is the foundation of stereolithography. The curing reaction is started by delivering UV light energy, and there are two transitions that occur throughout the process: gelation and vitrification. Gelation is a liquid-to-rubber transition in which viscosity is dramatically increased. Both the gel phase and the sol phase coexist in the system throughout this transition. Vitrification is a slow, thermo-reversible process that transforms liquid or rubber resin into a glassy solid resin(Huang et al., 2020). SLA has gone through four generations of technical advancement since then. Researchers have built a variety of physical methods to improve stereolithography performance using diverse technologies. We can print complex items with several orders of magnitude in scale utilising a variety of materials with these methods.



Figure 2.9: The top-down projection stereolithography system (Huang et al., 2020)



Figure 2.10: Stereolithography printed sample of dental prosthesis (Source https://decisionsindentistry.com/article/stereolithography-future-dental-fabrication/)

2.3.2.1 Advantage of SLA

Stereolithography is a solid freeform fabrication technique that is particularly versatile with respect to the freedom of design of the structures that are to be built, and to the scales at which these can be built. It has a strong prospective for biomedical applications. Live/dead assay on human dermal fibroblasts encapsulated in the gel. It has proven to facilitate, speed up, and improve the quality of surgical procedures such as implant placements and complex surgeries. Also, anatomically shaped implants and tailormade biomedical devices, such as hearing aids, have been prepared using stereolithography. The development of new resins has enabled to directly fabricate implantable devices like biodegradable tissue engineering scaffolds. With the introduction of hydroxyapatite composites, peptide-grafted structures, cell-containing hydrogels and modified natural polymers, stereolithography has developed into a broadly applicable technique for biomedical engineering purposes (Melchels et al., 2010).

2.3.2.2 Disadvantages of SLA

One of the disadvantages of SLA is that it requires support structure. Other than that, SLA requires post-processing. The post processing includes the removal of supports and unwanted material. This will prolong the time and can be quite tedious. Last but not least, the post for photo-curable resin is high. This may lead to increase in the cost when produce part using SLA Most of the available stereolithography resins are based on low molecular weight, multi-functional monomers, and highly crosslinked networks are formed. These materials are predominantly glassy, rigid and brittle. Only few resins have been described that allow the preparation of elastomeric objects by stereolithography. These resin formulations include macromers with low glass transition temperatures and relatively high molecular weights (1e5 kg/ mol), often in combination with non-reactive diluents such as Nmethylpyrrolidone (NMP) or water to reduce the viscosity of the resin (Melchels et al., 2010).

2.3.3 Selective Lase Sintering (SLS)

SLS (selective laser sintering) is a powder bed fusion method that uses laser energy to selectively heat powder particles, resulting in partial powder melting, particle fusion, and solidification to produce a 3D structure based on computer-aided design (CAD). It removes the requirement for a wide range of excipients and solvents, and it can produce solid oral dosage forms of various shapes and sizes in a single step with great accuracy, with the added benefit of feedstock reprocessing and recycling (Lekurwale et al., 2022). SLS allows for the management of numerous process parameters like as feed bed temperature, print bed temperature, laser power, layer thickness, and hatch spacing to create things with controlled compression, porosity, and interior structures.

Manufacturing businesses aiming to deliver their new customized products more quickly and gain more consumer markets for their products will increasingly employ selective laser sintering/melting (SLS/SLM) for fabricating high quality, low cost, repeatable, and reliable aluminium alloy powdered parts for automotive, aerospace, and aircraft applications(Olakanmi et al., 2015). The particles lie loosely in a bed, which is controlled by a piston, that is lowered the same amount of the layer thickness each time a layer is finished. SLS was initially developed at the University of Texas at Austin. SLS is a process in which a high energy laser beam scans the surface of a powder bed (the powder can be metal, polymer or ceramics) and the melted powder solidifies to form the bulk part. Example of the part produced through STL process is shown in Figure 2.11 below.



Figure 2.8: Pneumatic Gripper (TPU 92A-1) for ABB's dual-arm robot, YuMi (https://www.materialise.com/en/manufacturing/3d-printing-technology/laser-sintering)

2.3.3.1 Advantage of SLS

The main advantages of this technology are the wide range of materials that can be used. Unused powder can be recycled. SLS technology is one of the leading AM techniques due to its advantages compared with other AM processes such as SLA. SLS distinguishes itself by producing parts from difficult-to-manufacture materials such as Titanium and Nylon. The SLS technique does not necessitate the use of any extra support materials because the powder acts as a support material (Kulkarni, 2015). This process offers a great variety of materials that could be used: plastics, metals, combination of metals, combinations of metals and polymers, and combinations of metals and ceramic (Wong & Hernandez, 2012).

2.3.3.1 Disadvantage of SLS

The disadvantages are that the accuracy is limited by the size of particles of the material; oxidation needs to be avoided by executing the process in an inert gas atmosphere and for the process to occur at constant temperature near the melting point. This process is also called direct metal laser sintering(Wong & Hernandez, 2012). The post-processing of the created part is a time-consuming procedure that necessitates the usage of machining. The processing materials are restricted. SLS metal components are still only used in a restricted number of industrial applications. Other metals, such as aerospace-grade aluminium, are being developed (Kulkarni, 2015).

2.4 Metal 3D Printing Technology

3D metal printing is a type of additive manufacturing that creates three-dimensional metal items layer by layer. The process works by sending a digital data file to a computer, which subsequently produces the component. Metal additive manufacturing creates complex pieces without the design limits associated with traditional production processes. Additive manufacturing (AM) is a relative newcomer when compared to machining and other traditional metalworking methods. Metal components could not have been created with 3D printing just a few years ago. They may now be made to high standards utilising a variety of metal powders(Asnafi et al., 2019). 3D metal printing is no longer only a prototype technology. It is increasingly utilised to manufacture components for the most demanding purposes. In traditional manufacturing, making metal parts is a wasteful process. When aircraft manufacturers make metal parts, as much as 90% of the material is cut away. Using the 3D process, less energy is used and waste is reduced to a minimum. Finished 3D printed products can be up to 60% lighter than their machined counterparts(Wani & Abdullah, 2020). Metal 3D printing is regarded as the pinnacle of 3D printing. Nothing compares to metal in terms of strength and durability. DMLS (direct metal laser sintering) was the first patent for metal 3D printing, and it was submitted in the 1990s by the German firm EOS. Since then, engineers have developed new processes for printing with metal, some of which are completely unique. KALMALAYSIA MELAKA



Figure 2.9: Metal printing process (Source<https://www.belmontmetals.com/alloys-and-powder-specs-for-3d-printing/)

2.4.1 Types of 3D printed Metal

Metals and alloys used in 3D metal printing provide businesses a low-cost option for creating components for a wide range of industries and applications. Nickel-based super alloys such as Inconel, copper alloys, cobalt-chrome alloys, titanium alloys, aluminium alloys, stainless steels, precious metals such as gold and silver, and tool steels are examples of common metal materials. Some producers may also create metal powders for specialised use. Table 1 below the following characteristics and properties for the following metals:

Table 2.1: Characteristics and properties for 3D printed metals	
(Source <https: alloys-and-powder-specs-for-3d-p<="" td="" www.belmontmetals.com=""><td>rinting/)</td></https:>	rinting/)

Metal Type	Properties
Nickel-Based Super Alloys (Inconel)	Nickel-based super alloys are ideal for components that will be exposed to high temperatures and corrosion. Inconel can endure temperatures of up to 1200oC and is good for weather and salt water corrosion because to its strong resilience. Nickel-based super alloys have excellent mechanical qualities, making this metal powder appropriate for a wide range of commercial applications.
Titanium Alloys	applications. Titanium alloys are recommended for components used in the medical industry due to their biocompatibility. It is very resistant to corrosion caused by human body fluids and will not create adverse health effects because it may be produced into implants. Titanium alloys also have minimal thermal expansion and a high strength-to-weight ratio, making them ideal for a variety of applications.

Cobalt-Chrome Alloys	Like titanium, cobalt-chrome alloys are also
	biocompatible. These extremely hard alloys
	are desired for applications where there
	needs to be excellent wear and corrosion
	resistance.
Aluminum Alloys	Aluminum alloys are often selected when the
	weight of the finished material is a
	consideration. They have high electrical
	conductivity and mechanical and thermal
	characteristics. These alloys are also light in
	weight. One disadvantage of aluminium
	alloy powders is their low hardness, which
ALAYS!	may cause component fatigue in applications
AL WALLAND AND	with high stresses or loads.
Stainless Steels and Tool Steels	For situations where the 3D printed product
F	requires high strength and hardness qualities
	for higher wear resistance, stainless steels
* SAINO	and tool steels (carbon and alloy steel types)
Malunda Kaic	are typically used. These metals are also
	ductile for applications and have high
UNIVERSITI TEKNIKAL MA	weldability.
Pure Copper & Copper Alloys	Despite the fact that copper has high
	electrical and thermal conductivity, it is not
	widely utilised in additive manufacturing.
	Copper alloys and pure copper, due to their
	surface qualities, will reflect laser energy of
	1-micron wavelengths back to the apparatus,
	causing machine damage. Furthermore, the
	material rapidly absorbs infrared light as it
	undergoes an unstable and intermittent re-
	melting process. However, organisations
	like as NASA are shifting their focus to the
	development of novel copper alloys and the
-----------------	--
	use of green lasers with 515 nm wavelengths
	in 3D metal printing applications.
Precious Metals	Precious metals such as gold, silver,
	palladium and platinum are used in jewellery
	making applications. These metals can
	provide an aesthetically pleasing finish for
	applications where delicate and geometric
	features are desired.



2.4.2 3D metal printed samples

Most powder-bed based additive manufacturing systems use a powder deposition method entailing a coating mechanism to spread a powder layer onto a substrate plate and a powder reservoir. Once the powder layer is dispersed, a 2D slice is bound together (3D printing). An energy beam can also be directed to the powder bed to melt the powder. Direct process powder bed systems are branded as laser melting processes and are available under different trade names such as Selective Laser Melting (SLM), Laser Cusing and Direct Metal Laser Sintering (DMLS)(Asnafi et al., 2019). The requirements of the user will decide on the choice of machine with the type of laser unit, powder handling and build chamber being some of the foremost features of the system to take into account. There is a variety of metal material that is available for metal 3D systems. The most common materials used are stainless steel, aluminium, nickel, cobalt-chrome and titanium alloys. Other materials are tool steels, nickel-based alloys, precious metal alloys, and copper alloys. When deciding on a material, properties such as tensile strength, hardness and elongation are important. Because there is a wide variety of material, the right material for a project can be easily factored in the specification of a product. Figure 2.9 shows first 3d printed metal supercar where it exhibits precise metal printing(Blakey-Milner et al., 2021). On the other hand, Figure 2.10 shows the aviation part of 3D printing where they manufactured the fan of an airplane. Lastly figure 2.11 exhibits the beauty of 3d printed jewellery using metal 3D

printing UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Figure 2.9: Metal printed supercar (Source<https://3dprint.com/74810/3d-printed-supercar-blade/)



Figure 2.10: Metal printed aviation fan

(Source<https://www.eos.info/en/all-3d-printing-applications/aerospace-3d-printing/airbus-case-study)



Figure 2.11: metal printed jewellery (Source<http://www.alienology.com/catalog/?p=431)

2.4.3 Advantages of Metal printing

It's almost boundless when it comes to manufacturing objects with a complicated shape. advantages of 3D printing with metal includes a few of these features:

- 3D printers can manufacture complicated details much quicker than traditional methods of manufacturing such as CNC and metal casting
- Parts that requires intricate and small parts are more achievable compared to traditional methods.
- More intricate shapes allow the part to be lighter without compromising strength. This is why 3D printed parts are so popular in the aircraft sector.
- Metal printed parts are very conservative in the waste sector wich makes it more efficient.
- It's possible to 3D print details in assembly, and as a result, save even more time and money.

2.4.4 Disadvantages of Metal Printing

As wonderful as 3D printing is, it is not without flaws. To begin with, it is not as quick and inexpensive for regular and basic parts as traditional techniques of manufacture. Forming is preferable for conventional U and V forms, especially in big quantities. Other limitations of metal 3D printing include:

- Filaments and powdered metals are much more expensive compare to regular raw materials
- Speed of production is comparatively slow for regular objects.
- Tolerance and precision are usually lower in comparison with CNC machining
- Metal 3D printers are expensive and require special skills and training.
- Designing for metal 3D printing can be more complicated in comparison to other manufacturing methods.

2.5 Advantages and Disadvantages of AM

Additive manufacturing (AM), also referred to as 3D printing, has gained popularity in media and captured the imagination of the public as well as researchers in many fields. With recent interests, this technology is continuously being redefined, reimagined and Additive manufacturing technologies are opening new opportunities in the terms of production paradigm and manufacturing possibilities (Gao et al., 2015). Manufacturing lead times will be reduced substantially, new designs will have shorter time to market, and customer demand will be met more quickly (Attaran, 2017). Building time for conventional machine depends on the features of design. If the design contains more features, the numbers of building steps are increased together with building time. Moreover, AM reduces tooling cost as there is no tool required for AM process (Gibson & Rosen, n.d.).

In terms of industrial machinery, assembly procedures, and supply chains, AM technologies have the potential to have a considerable influence on existing production patterns. Such innovations, if effective, can streamline their manufacturing value chain by removing them from third-party suppliers, improving performance, and extending the usable life of their engines. Smaller businesses and end-users can benefit from AM by transforming themselves into self-sufficient "designers and manufacturers," capable of developing novel products and manufacturing processes(Gao et al., 2015). The increasing diversity of materials, low-cost equipment, and possibility for new application areas are driving the fast spread of additive manufacturing technology. The technology is advancing and has penetrated a variety of areas. It is currently employed in prototyping and distributed production, making AM more accessible to the next generation of users. Technology is progressively resurfacing as a significant tool for increasing internal efficiency. It's currently one of the most talked-about and intriguing developments in the world of design and marketing(Attaran, 2017). Although highly sought as the advancement of the engineering world it still comes in few downsides and upsides. Table 2.2 exhibits the advantages and disadvantages of AM.

Table 2.2: Advantages and challenges of additive manufacturing (adapted from (Berman, 2012), (Gao et al., 2015), (Yoo et al., 2016) and (Petrovic et al., 2011)).

Advantages	Disadvantages
• Small batches of customized products are economically	• Cost and speed of production
attractive relative to traditional mass production methods	 Changing the way that designers think about and approach the use of additive manufacturing
 No switch over costs because direct production of 3D CAD models does not require any tools and molds. Designs in the form of digital files can be easily shared, 	 Removing the perception that AM is only for rapid prototyping and not for direct component and product manufacture Development and standardization of new materials
 facilitating the modification and customization of components and products UNIVERSITITEKNII The additive nature of the process 	 Validation of the mechanical and thermal properties of existing materials and AM technologies
gives material savings, as does the ability to reuse waste material (i.e. powder, resin) not used during manufacture (estimated at 95–98% recyclability for metal powders)	 Development of multi-material and multi-color systems Automation of AM systems and process planning to improve
• Novel, complex structures, such as free-form enclosed structures	 Post-processing is often required. This may be due to the stair stepping effect that arises from

and channels, and lattices are achievable

- Final parts have very low porosity
- Making to order reduces inventory risk, with no unsold finished goods, while also improving revenue flow as goods are paid for prior to being manufactured
- Distribution allows direct interaction between local consumer/client and producer

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incrementally placing one layer on top of another, or because finishing layers are needed

- Support structure materials cannot be recycled so need to be minimized through a good buildup orientation
- Intellectual property issues, particularly regarding copyright
- Deficits in designers and engineers skilled in additive manufacturing
- Non-linear, localized collaboration with ill-defined
 roles and responsibilities

UNIVERSITI TEKNIKAL•MContinuously changing set of competitors

2.6 Applications of AM

a. Lightweight Machine

It is possible to form lightweight components using AM technology. The primary objective of the automotive and aerospace industries is to create the lightest possible automobile or aircraft while maintaining safety. AM technologies have made it possible to create complicated crosssectional regions such as the honeycomb cell or any other material part with cavities and cutouts that lower the weight-to-strength ratio. It is feasible to make lightweight structures; methods such as the hanging method and the soap film method can be used to get a form with minimal weight. Because of its design freedom and capacity to create complicated and lightweight parts, it has a lot of potential in the aerospace sector. From the outset, additive manufacturing has been employed in aircraft applications. It has a significant impact on product design, direct component manufacturing, assembly, and maintenance in the aerospace sector, in addition to serving as a fast prototype technology that saves money and time during the product development process. AM is adequate to obtain efficient and lightweight frames for equipment like drone, even with innovative techniques such as continuous fiber reinforced composite AM. The flexibility offered by additive manufacturing could play a primary role in opening the path to innovative design solutions, (Palomba et al., 2022). Figure 2.12 shows the example of lightweight manufactured using AM.



Figure 2.12: 3d printed Drone (Source< https://3dprinting.com/how-to/3d-print-drone/>)

b. Architectural Modeling.

3D printing is still in its development in the field of architecture, but it is showing great potential. 3D printing is slowly but steadily becoming an important tool in the entire design and building process. The use of this technology in the construction of buildings has already had an influence on time, cost, worker safety, and the economy. When the buildings became quicker to construct due to mass production but lost their uniqueness and customizability. 3D printing can allow engineers to bridge the gap between mass production and customizability (Mathur, 2016). Architects may find it challenging to create an architectural model. Architects often create their models by hand, but creating a physical model while complicated models are on their thoughts might be difficult. The architects must model in order to examine the models and their usefulness. They are also required for architects to explain them to their clients and persuade them to proceed with the project. Architects may benefit from AM technology by being able to generate physical models faster and without having to worry about the intricacy of their designs. It also produces a higher resolution than other architectural procedures. Processes such as DLP process allows manufacturers to accelerate the development of architectures that make quick adjustments to complex objects and produce highly detailed and customizable structures (Lim et al., 2022). Figure 2.13 shows the example of architectural buildings constructed using AM.



Figure 2.13: 3D manufactured buildings

(Source< https://iaac.net/educational-programmes/applied-research-programmes/otf-3d-printing-architecture/)

In the medical field, AM printing has a wide range of uses. They're revolutionizing medicine by allowing doctors to create quick prototypes and high-quality bone grafts, as well as patientspecific models of damaged bone for study. AM printing technology allow doctors to scan and produce a physical model of a patient's damaged bones, giving them a clearer concept of what to expect and better planning the treatment. This saves money and time while also helping to obtain a better result. Bone grafts may now be printed, and AM techniques make it feasible to have a transplant that is almost similar to the original. Doctors can build a porous-controlled substance that allows osteoconductive or a precise metal transplant that is equal to the original depending on the bone to be replaced due to the indefinite form or shape of what may be constructed. The density, pore shape and size, and pore interconnectivity of the transplants are crucial characteristics that will affect tissue development and the mechanical properties of the implant bone (Bose et al., 2013). 3D printing is becoming more sought-after due to its potential to straightly print porous scaffolds with specific designed shape and interconnected porosity. In the field of bone tissue engineering, it is proven that some of these inorganic biodegradable scaffolds are ideal to the particular field. 3D printing has the advantage of rapidly fabricating customized medical models at a lower cost. Figure 2.14 is an illustration of a cancer fighting beads. In medical field, 3D printed parts are also widely used in making the human anatomical model kits and 3D printed leg. This is shown in Figure 2.15 and 2.16.



Figure 2.14: Beads containing antibacterial or cancer-fighting compounds (Source<https://www.disabled-world.com/news/research/3d-printing/implants.php/21/8/2014)



Figure 2.15: 3D printed human anatomical model kits, (a) head and (b) arm (Source<https://www.sciencedirect.com/science/article/pii/S2095809917306756?openDo wnloadIssueModal=true/21/7/2018)



Figure 2.16: 3D printed leg (Source<https://advancedmanufacturing.org/3d-printing-orthotic-prostheticdevices/7/8/2015)

d. Sports Application

With the use of novel equipment to break new records, the benefits of adopting 3D printing are progressively becoming realized by the sports industry. Technology is increasingly being used in a variety of sports, including auto racing, football, cycling, and golf. The goal of technology is to increase competitiveness and innovate. Sports also make use of 3D printing. Race teams, for example, require a car that is both quick and light. 3D printing may be used to create complex and bespoke items. 3D printing was used to create the Nike Zoom Superfly Flyknit sneaker seen in Figure 2.17. Aside from that, shin-guards are made using 3D printing. 3D-printed shin guards provide more protection, allow for more design modification, and are lighter. 3D printers are mostly utilized to create protective sports equipment. Figures 2.18 and 2.19 demonstrate how 3D printers are commonly used to create protective sports equipment such as helmets, mouth guards, and knee guards. Prosthetics for impaired athletes were also created using 3D printers.



Figure 2.17: Nike Zoom Superfly Flyknit for American athlete Allyson Felix (Source<https://www.3dnatives.com/en/3d-printing-sport-201220174/28/11/2017)



Figure 2.18: 3D printed shin-guard (Source<https://www.3dnatives.com/en/top-10-3d-printing-sport-131120174/22/112017)



Figure 2.19: Football protection mask and mouth guard (Source<https://www.digitaltrends.com/cool-tech/ufc-guardlab-custom-3d-printed-mouthguards/16/3/2016)

e. Electronic Applications

3D printing in electronic industry a unique technology that potentially offers a high degree of freedom for the customization of practical products that incorporate electrical components, such as sensors in wearable applications. The fabrication of 3D-printed sensors is carried out in a seamless manner by either inserting a sensor into printed objects or inherently printing the complete sensor. In recent years, more of the current research on 3D-printed sensors has focused on specific fields including electronics, force, motion, hearing, optics, and so on. Other sensing categories are often built by integrating commercial components into 3D-printed structures. Electronic and force sensing modules are particularly well suited for 3D printing. (Xu et al., n.d.). Filaments with resistivity of ~5 × 10–3 Ω m were used to 3D print Practical Circuits. The circuit was powered up with a 9 V battery. To illustrate the potential of the material used for sensing application, a plastic thermometer and a flex sensor were also prototyped (Kwok et al., 2017). Figure 2.20 and 2.21 shows the example of 3D printed sensor and electronic device.



Figure 2.20: 3D printer Flex Sensor (Robert et al., 2012)



Figure 2.21: 3D printing of capacitive interface device (Robert et al., 2012)



2.7 Dimensional Accuracy

The dimensional accuracy of a component, the degree of agreement between the manufactured dimension and its designed specification, it is the most critical aspect for ensuring the dimensional repeatability of manufactured parts. The degree of agreement between the produced dimension and its intended specification is defined as dimensional accuracy of a component part. It is the most important factor in assuring the dimensional consistency of produced component components. The goal of this research is to look at the dimensional correctness of a common component part created using the 3D printing technology. (Islam et al., 2013). The dimensional accuracy of a component part is evaluated through its size (size tolerance) and shape (geometric tolerance, including form, orientation, and location). Dimensional accuracy is the factor which shows how close the dimensions of the product is to that of the ideal product. It is the quantitative values from machine manufacturers and material suppliers that state the expected accuracy of parts.

All tolerances stated are with respect to well-designed parts on well calibrated machines. Caliper, micrometers smart scope and coordinate measuring machine can be used to check the dimensional accuracy of the product. Tolerance refers to the total allowable error within an item, whether it is above or below the desired value. It is usually represented as a +/-value off of a specification. Due to changes in temperature and humidity which will lead to material expansion and contraction, the products can deform. As such, it is necessary to take errors into consideration with regard to design values in the manufacturing and inspection processes. It is deemed unacceptable if the error does not reside within the allowable tolerance.

2.7.1 Factors affecting Dimensional Accuracy

The dimensional precision of 3D printed items is critical when producing huge assemblies or pieces that must fit together properly. Many common factors can have an impact on its accuracy. Because of the large range of parameters involved, establishing (or defining) an achievable dimensional accuracy value in these technologies is a difficult task. This technology's tremendous flexibility (in terms of shape, materials, methods, form and size of the powder particles, post-processing procedure, and so on) produces a significant degree of uncertainty on the final product quality. This uncertainty impacts not just the surface roughness or mechanical qualities, but also the ultimate product quality. This uncertainty not only impacts surface roughness or mechanical accuracy, even without considering further post-processes.(Cuesta, 2020). Below are te few factors affecting the dimensional accuracy of 3D printed products:

- Machine accuracy
 - Some 3D printers are simply more accurate than others. Some machines provide standard dimensional accuracies for well-designed parts made on a wellmaintained machine while some older machines struggle to produce highly accurate products.
- Materials
 - Choosing the correct material for your object will greatly increase the accuracy to which it can be printed. For example, Standard SLA resin has a high dimensional accuracy compared to flexible SLA resin which greatly differs in the final result's accuracy
- Warping and shrinkage
 - The techniques used in 3D printing can cause materials to warp and shrink. Large expanses of material, flat surfaces, and unsupported structures are all susceptible to warping and should be highly regarded to avoid poor accuracy.
- Object size

- In general, small objects can be printed with higher accuracy than large ones. Bigger objects have more room for manufacturing errors.

2.7.2 Improving Dimensional Accuracy

Dimensional measurement is critical for interchangeability and worldwide trade. It is how we guarantee that everything fits together properly. Globalized industry would not be viable without worldwide length standards as the foundation for standardized parts (Beslagic & Varda, 2022). Dimensional measuring is also essential for ensuring that things work as expected. Structure strength, for example, is determined using data such as flange thickness or beam span. Uncertainty in these measurements raises the uncertainty in the strength(Hanon et al., 2021). This is vital for safety-critical constructions which requires pin point precision in their builds. Thus, improving dimensional accuracy of printed parts needs to be constantly kept in mind in order to maintaining the dimensional accuracy and integrity of products. Below are a few ways to improve the dimensional accuracy of 3D printed parts:

- Performing machine's calibration test
 - When you've never used a 3D printer or filament before, it's nearly difficult to forecast how well it will meet your dimensional accuracy needs. The easiest way to get relevant data would be to print a tiny calibration cube. Recalibration is recommended if the discrepancy between the two dimensions variables is higher than 0.5 millimeters
- Reduce printing temperature and flow rate
 - Small traces of stringing or blobs might drastically harm the ultimate outcome if you're trying to improve the precision of your print. To avoid this, consider lowering the printing temperature by 5 degrees Celsius and the flow rate by 5% increments. This should help lessen the impacts of heat contraction and reduce the likelihood of warping.
- Use support structures
 - A method to prevent semi-solid molten material from collapsing or drooping under its own weight by employing supports. This is particularly the case for overhangs, even if they adhere to the 45-degree guideline. The two option of employing a soluble support material (either HIPS or PVA) will be the most viable option for 3D printing.

2.7.3 Dimensional accuracy Measurement Tools

When producing high-precision components and machinery, it is critical to ensure that each component meets the dimensions and tolerances set by the design engineer. The type of dimensional inspection instrument utilized for a certain application is determined by several criteria, including The level of accuracy required, whether or not the object can be touched during the measurement process, the physical and surface characteristics of the object and the transparency or opaqueness of the object(Cuesta, 2020) Below are the six equipment than can be used for inspection equipment:

- Pneumatic Gauging
 - These gadgets, commonly known as air gauges, use the restriction of air and the subsequent change in flow or pressure to measure a dimension, often an outer diameter or hole. Air gauging is a quick, non-contact inspection procedure that is often used for workpieces with tolerances of 0.005" or less. The measurement's resolution and repeatability may be measured in millionths of an inch. Because many applications need part-specific tooling, air gauges are often used to measure manufacturing components that are manufactured on a regular basis.



Figure 2.22: Pneumatic gauging (Source<https://encyclopedia2.thefreedictionary.com/Pneumatic+Gauge)

- Hand Tools
 - These are the most fundamental and ubiquitous types of measuring equipment. Hand tools continue to be quite effective in the majority of dimensional inspection applications. Dial indicators, digital calipers, micrometers, and tape measurements are frequently the best choice since they are very portable, widely available, and inexpensive.



Figure 2.23: Hand tools for dimensional accuracy measurement (Source<https://www.qpluslabs.com/blog/top-10-tools-for-starting-a-machine-shop/)

- Coordinate Measuring Machines (CMM)
 - These range from small lightweight arms to massive, heavy machines with granite constructions that need particular foundations and regulated settings. In most circumstances, a contact probe is programmed or moved manually until it comes into contact with the surface to be measured. The computer in the CMM translates the physical position to a digital location inside the multi-axis coordinate system of the system. These systems vary widely in terms of cost, work envelope, precision, and repeatability; nonetheless, some CMMs may cost upwards of a million dollars and measure massive items to an accuracy of a few microns. Touch probes cannot be used on items having an elastic surface, surfaces that are too delicate to touch, or surfaces that are too clean to touch during the measuring procedure. There are non-contact optical probes available for many modern CMMs that can be used in these situations.



Figure 2.23: Coordinate Measuring Machine (Source<https://www.mitutoyo.com/products/coordinate-measuring-machines/)

- Optical Systems
 - The size, magnification, and accuracy of these devices varies. Whether the system is a desktop-size measuring microscope or a massive optical comparator, light and optics are used to calculate a dimension based on the profile of the item inside the instrument's field of vision. By adding an overlay or measuring reticle, these systems may also be utilized to compare an object to a specified standard form or measurement.



Figure 2.24: Image Dimension Measuring System (Source<https://www.keyence.com.my/products/measure-sys/image-measure/lm/)

- Light-Based Systems
 - Another type of non-contact inspection makes measurements on the workpiece using structured light (LED) or laser line triangulation. Structured light scanners construct a comprehensive 3D point cloud of stationary item geometry by taking a series of photos with varying patterns of light projected onto the object surface. Errors in findings might arise if the item moves considerably during the data gathering procedure. The performance of these devices can also be affected by ambient light. As the item goes past the sensor's field of vision, laser line triangulation scanners capture a series of profiles from the laser line.



(Source<https://www.acuitylaser.com/by-measurement-type/thickness-measurement/). UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.8 Technologies used to improve surface finish

2.8.1 Ultrasonic Assisted Machine (UAM)

Ultrasonic assisted machine (UAM) technology has been applied in many subtractive manufacturing areas since its development. It utilizes the piezoelectric transducer. Ultrasonic piezoelectric transducers can convert electrical energy into mechanical energy. Kazimi (2017) states that the ultrasonic assisted machining is an advanced technology for improving the machining process and increasingly used in many industrial applications as it is proven to be a technology that is able to improve the quality and surface finish of products. UAM technology has been applied in many subtractive manufacturing areas since its development.

UAM can be performed by vibrating the workpiece, actuated work system (AWS) or the cutting tool; the actuated tool system (ATS) and they do exhibit some differences in behavior (Kadivar et al., 2014). However, for large components, actuating the work piece can be an issue. The materials of the workpiece used in UAM do not have to be a good conductor of electricity. The effect of ultrasonic grinding of Ti6Al4v alloys at a frequency of 20 kHz applied onto the workpiece varied on the variables. Their result shows an evident improvement of the surface roughness of workpiece. Ultrasound is a technology that is proven to be used thoroughly for machining and also been claimed to enhance surface quality of the workpiece(Kadivar et al., 2014).

2.8.2 Vapor Smoothing Process

In order to improve the surface finish of the FDM based benchmarks through chemical (acetone) exposure by using vapor smoothing station (VSS). Acetone vapor bath smoothing is a potent solution for the post processing stage in FDM (Lalehpour et al., 2018). Acetone vapor smoothing dissolves a print's surface using gaseous acetone. The 3D printing layer lines are blended together in this acetone solution, resulting in a smooth, lustrous finish. Because acetone evaporates swiftly even at ambient temperature, this procedure may be done slowly and without the need of heat.Despite the fact that VSS has been shown to increase surface polish by nearly 15 times, the use of a costly standard volatile fluid in this process continues to be a barrier to its use. The benchmarks were refrigerated for 10 minutes in the VSS refrigeration unit before to exposure to volatile acetone vapor environment (AVE) in chemical treatment. The benchmark patterns were hung within the heating chamber after cooling, where volatile acetone chemical fumes re-flowed the material. The standards were placed in the refrigerated for another 10 minutes to allow for the fixing of re-flowed material.

2.8.3 Ultrasonic Nano-Crystal Surface Modification

An innovative surface processing technique is the ultrasonic nano-crystal surface modification (UNSM). UNSM is used to alleviate the potential for the Ni ions release. UNSM can notably enhance the surface finish and reduce the porosity of the surface by concurrent ultrasonic striking and burnishing (Cabanettes et al., 2018). The tungsten carbide tip contacts the sample surface during the UNSM process, which occurs at a high frequency (20 kHz), while scanning the surface along pre-designed routes to impose a burnishing effect. Under the impacts of static and dynamic loads, the tip is sustained in touch with the sample while simultaneously producing ultrasonic striking and burnishing on the sample surface. The UNSM process includes process parameters such as tip diameter, static load, ultrasonic vibration amplitude, distance between neighbor scans (interval), scanning speed, and treatment cycles. UNSM also causes plastic strain, which hardens the top layer. The synergistic effect of better surface finish, lower

subsurface porosity, and a hardened surface layer is to produce a higher wear and corrosion resistance.

2.9 Process Parameters of 3D printer

2.9.1 Layer Thickness

The layer thickness is one of the most important technical characteristics of any 3D printer; it is essentially the vertical resolution of the z-axis. The layer height of each subsequent addition of material in the additive manufacturing or 3D printing process in which layers are stacked is measured by layer thickness in 3D printing. Due to technical differences, not all 3D printers are created equal; each 3D printer outputs a varied layer thickness. Figure 2.26. depicts the layer thicknesses created by a 3D printer. The highest layer thickness is often approximately 150m, with a minimum of 16m. A 3D printer's exact height of each layer of plastic extruded, cured, or sintered. This option is changed using a slicer application, and it has many more implications for the final print than one may assume. When used correctly, this parameter will improve the speed, quality, and smoothness of your print. Prior to printing, the 3D printer's layer thickness parameters can be modified. Selecting a layer height is not as critical for some printing techniques (such as SLS, Material Jetting, or SLM/DMLS), either their default resolution is suitable for most applications, or the layer height is already pre-set by the machine maker. Layer height is a significant design parameter for various techniques (such as FDM and SLA) that affects printing time, cost, aesthetic appearance, and physical qualities of a printed item.

	mekness for various 5D primers	
Printer/ Technology	Layer Thickness	
Professional fused deposition modelling for	0.17 mm to 0.33 mm (0.007" to 0.013")	
production (Stratasys, etc.)		
Office or fablab fused deposition modelling		
(Makerbot, Ultimaker, etc.)	0.10 mm to 0.33 mm (0.004" to 0.013")	
Selective laser sintering (SLS) – (EOS, 3D	0.060mm to 0.150 mm	
System)		
Resin deposit (Stratasys Polyjet)		
	0.016mm to 0.028 mm	
Material binding (3D Systems ZPrinter)	0.1 mm	
Stereolithography, DLP, resin hardening by	0.05 mm to 0.15 mm	
light or		
Wax deposition by piezoelectric head	0.005 mm to 0.10 mm	
(Solidscape)	JIEW	
SAINO -		
اونيوم سيتي تيكنيكل مليسيا ملاك		
3D printer nozzle		
all and		
	Printing \$layer	
0.05 mm 0	1 mm 0.2 mm 0.3 mm	

Table 2.3: Max and min layer thickness for various 3D printers



2.9.2 Raster angle

The raster angle refers to the angle between the path of the nozzle and the X-axis of the printing platform during FDM. The raster angles between two adjacent layers differ by 90°. The raster angle affects the forming accuracy and the mechanical performance of the printed sample. Generally, the raster angle can be selected from 0° to 90°. (Samples, 2017). The samples printed at raster angles of 0°/90°, the filaments are oriented parallel to the load direction, thus, making the strongest sample. Figure 2.27 explains the raster angle of the 3D printed samples.



(Source<https://www.mdpi.com/2073-4360/13/14/2289/htm)

2.9.3 Bed Temperature

Heated beds are crucial to 3D printing. The bed temperature must be set to certain temperature. Not all 3D printers have heated bed. Even though the recommended PLA print temperature is 70°C, this doesn't always work. In general, the optimal printing of PLA temperature ranging from about 185°C to about 205°C. In order to print with ABS, a temperature control bed is needed. The recommended bed temperature for ABS is 110°C. Table 2.4 below shows the ranges of temperature for 3D printing:

Material Extruder Temp. Bed Temp. PLA AYSIA 195-210 Celsius 70 Celsius ABS 240-250 Celsius 115 Celsius Ninja Flex 220-230 Celsius 40-50 Celsius Nylon 230-265 Celsius 115 Celsius PC 250+ Celsius 125-130 Celsius HIPS 230 Celsius 80 Celsius **PVA** 200 Celsius **85** Celsius UNIVERSITI TEKNIKAL MALAYSIA MELAKA

 Table 2.4: Temperature bed for 3D printing

 (Source<https://3dplatform.com/getting-3d-prints-to-stick-to-the-printer-bed-3dprintingtechtips/)</td>

2.9.4 Printing Speed

Currently, the 3D printer supports three different types of printing rates. The first set prints at a speed of 40 to 50mm/s, while the second set prints at a speed of 80 to 100mm/s. In the meantime, the fastest set print speed is roughly 150mm per second. Some printers can print at speeds exceeding 150 mm/s.s. Lower product quality is associated with faster printing speeds. When the speed exceeds 150mm/s, the printed product's quality suffers significantly. At such a fast speed, the filament will also likely to slide, posing a challenge for the user.

2.10 Summary

In a nutshell, the entirety of this chapter focuses on the topics that relates to AM from the initial process up to the finishing process of the printing. AM refers to the technique of combining materials to construct a three-dimensional model. These materials are linked layer by layer, which challenges subtractive manufacturing's material removal process. AM is currently widely utilized in a variety of industries because, when applied appropriately, it may save production costs and time. The seven basic steps are part of the AM's functioning principles. The process begins with the creation of a CAD model of the design, which is followed by the conversion of the CAD to an STL file, STL slicing, machine setup, 3D printing, removal, and finally post-processing. There are various varieties of AM systems, each with its own set of advantages and disadvantages. The SLA is the most wellknown and commonly utilized AM method. SLA is a bit pricey, but it comes in useful when it comes to speed; items manufactured using SLA may be made in as little as one day. The SLS is another form of AM system. It is a process that employs a laser as a power source to sinter powdered material. SLS printed pieces are generally self-supporting, however the porous surface of SLS produced parts need an extra coating step. FDM is one of the most widely utilized 3D printing techniques. There are various varieties of AM systems, each with its own set of advantages and disadvantages. The SLA is the most well-known and commonly utilized AM method. SLA is a bit pricey, but it comes in useful when it comes to speed; items manufactured using SLA may be made in as little as one day. The SLS is another form of AM system. It is a process that employs a laser as a power source to sinter powdered material. SLS printed pieces are generally self-supporting, however the porous surface of SLS produced parts need an extra coating step. FDM is one of the most widely utilized 3D printing techniques. FDM involves no chemical processing and is cost effective, although items created may experience unexpected shrinking. The benefits and drawbacks of the AM method are also discussed in this chapter. For example, AM can create complicated and personalized components, but it takes a long time and requires some post-processing. AM is used in a variety of fields. Lightweight mechanical, architectural, medicinal, and sports are all part of this discipline. This chapter then goes into dimensional correctness.

Dimensional accuracy is a metric that indicates how near the dimensions of a manufactured product are to the intended design tolerances. The UAM is one of the technologies used to improve the surface finish. It employs ultrasonic vibrations in a number of processes in order to improve product quality. Chapter 2 also includes the printing parameters of the 3D printer such as the raster angle, the bed temperature and also the layer thickness. The information in the literature review was obtained through intense journal reading and previous studies conducted by others.



CHAPTER 3

METHODOLOGY

This chapter will give an initial insight on the methods to be applied in order to ensure that the objectives of this project can be achieved. In order to explain the process of this project, a process flow chart was constructed. In conclusion, this methodology explained the project flow that has been carried out along the project duration.

3.1 Introduction

Metal 3D printing is one of the few printing samples that are lacking in data when it comes to the basis of 3D printing in the engineering world. Thus, an investigation is carried out in order to determine the dimensional accuracy of the 3D printed metal samples. The finding can be used to figure out the optimum parameters of the 3D printed metal samples in 3D printing process. In this chapter, the method which includes the way to produce the test-model and types of testing used are discussed thoroughly. In this project, a total of 8 test model will be made using two different materials.

3.2 Process Flow Chart



Figure 3.1: Process Flowchart

The flow of the project will be described by the following flow chart. This flow chart showed the clear path of the project from the start until finish. Figure 3.1 shows the overall flow of this study. Firstly, the major problem was identified through the process of problem identification. In order to have a better grasp on the fundamental knowledge regarding this particular topic, a research was conducted and the literature review was made. By using the CAD software, CATIA, the design process was carried out next. Stainless steel metal filaments will be picked for the project and the specific 3D printing machine that will be utilized is Fused Deposition modeling (FDM) Ultimaker. The ideal printing parameter will be determined by the machine using filament codes that is written on the filament. Upon completing the fabrication process, the 3D printed samples' dimensional accuracy was tested using the CMM. Parameters such as the length, width, height, thickness, corner radius, angularity and perpendicularity were checked using the CMM. Results and analysis were made prior to documentation.



3.3 Experimental Equipment

3.3.1 Fused Deposition Modeling (FDM)

The Ultimaker 3D printer was used to conduct the experiment with a built size of 330 x 240 x 300 mm build volume and 0.4 mm nozzle diameter to print the sample model. Due to its feasibility to achieve fine built parameters through lean layer thickness and road width, a nozzle with this particular nozzle was chosen. The smart and innovative machine comes in few features such as Advanced auto bed leveling and filament compatibility with over 200 materials. In addition, the printers were chosen due to its notoriety among the users as well as its accessibility, efficient operation and have low cost. Figure 3.2 shows the sample model of Ultimaker 3D printer with three axis which x, y and z.

To prepare the STL file of the sample model for building the FDM desktop, UP software was used. The part was developed layer by layer while the material solidifies rapidly and bond with the previous layer after it has been deposited through the nozzle. In this research the material that will be utilized is Stainless Steel. With a temperature of 270°C, the Stainless-Steel filaments were extruded through the heated nozzle with recommendations from the Cura software. Table 3.1 shows the specification of the Ultimaker 3D printer used.

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Table 3.1: Ultimaker's Specification	
Brand S	Ultimaker S3
Materials to be printed	-Stainless Steel - Tough PLA -ABS
Weight	20.6 kg
Dimension of the printer	330 x 240 x 300 mm

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The Standard Operating Procedure (SOP) of Fused Deposition Machine are as stated below:

- 1. The feeder guide (roll holder) was attached onto the back side of the printer.
- 2. Different types of filaments were prepared.
- 3. With the condition of filament coming out from the back of the roll/printer, the spool of the filament was loaded onto the roll holder.
- 5. The end of the filament was fed through the filament guide.
- 6. Then, the end of filament was pushed into the print head feed holes.
- 7. The USB cable and the power adapter were plugged onto the back of the printer.
- 8. The switch at the socket was turned on followed by the switch at the back of the printer.
- 9. The FDM machine's software was opened and then the "initialized" icon was clicked on.
- 10. After that, the "Print" icon was selected and the "Preference" icon was clicked on.
- 11. The following settings was selected:
- Z Resolution: "0.20mm" = Each layer's height UNIVERSITI TEKNIKAL MALAYSIA MELAKA
 - **Raster Angle:** 30 degrees
- 12. Next, the overall quality was selected
 - Normal = Average quality
 - **Fine** = Great quality but consumes a longer time
 - **Fast** = Takes less time but compromises the quality
 - Ð
- 13. The "OK" icon was selected and the printing process begins.
- 14. The residual base of the product was scrapped off
- 15. Once the process has completed, the power was turned off.
3.3.3 Coordinate Measuring Machine (CMM)

A coordinate measuring machine (CMM) is a device that measures the geometry of physical objects by sensing discrete points on the surface of the object with a probe. The probe position can be manually controlled by an operator or it can also be control by the use of a computer depending on the machine. The coordinate measuring machine is shown in Figure 3.2.

The three axes from the machine's coordinate system of the CMM works in a same way as our fingers as it traces map coordinates. Instead of a finger, the CMM uses a probe to measure points on a workpiece. To the machine's coordinate system, each point on the workpiece is unique. The typical 3D "bridge" CMM allows probe movement along three axes, X, Y and Z, which are orthogonal to each other in a three-dimensional Cartesian coordinate system.

Example of results obtained from CMM testing is clearly presented by Figure 3.3 with micrometer precision, each axis comes with a sensor which monitors the position of the probe on that axis. When the probe contacts (or otherwise detects) a particular location on the object, the machine samples the three position sensors, thus measuring the location of one point on the object's surface.



Figure 3.3: The Coordinate measuring machine

	ZEISS (Calypso	ZEISS
Measurement Plan D-M0P42-00485-1 SAMPLE	Date 1 March 12, 20	16	
Drawing No. * drawingno *	Time 1:17:43 pm	Order * order *	
Operator Master	CMM C32Bit	Incremental Part Nur 1	nber
Actual	Nominal	Upper Tol. Lower Tol.	Deviation
True Position 7.00			
0.0323	0.0000	0.1000	0.0323

Figure 3.4: Example of results obtained from CMM



3.4 Experimental Preparation and Procedure

3.4.1 Experiment Set up

By using the UP Plus 2 3D printer, all six samples with the dimension of 1.5 cm x 1.5cm x 1.5cm were printed out. In order to induce ultrasonic frequency vibration, the piezoelectric transducer was attached to the platform of the 3D printer along with a function generator. The Frequency was set to the desired range. The printed samples were then tested using the CMM. The geometries tested were, corner radius, length, thickness, angle, perpendicularity, width, height, hole diameter and also flatness. The results obtained was tabulated and compared with the desired dimension of the CAD drawing of the products. Figure 3.7 shows the set-up of the whole printing process.



Figure 3.5: Printing set up

3.5 Dimensions measured



Figure 3.6 Preview of the sample



Scale: 2:1

Figure 3.7: Drafting of the Design



Figure 3.8: Printed sample



Figure 3.5 displays the drawing of the design whereas figure 3.6 depicts the drafting of the drawing. Figure 3.7 shows the printed sample that was later measured using the CMM. There were several measurements taken. The lists of geometries are as follow:

Table 3.2: Geor	metry accuracy
Geometry	Dimension 9. 100 Dimension
Thickness UNIVERSITI TEKNIKA	L15mmLAYSIA MELAKA
Corner Radius	10mm
Angle (Chamfer)	45°
Perpendicularity	90°
Hole Diameter	10mm
Flatness	Pass/fail

3.6 Summary

This chapter describes the proposed methodology of this research which consists of the principles method that has been done to complete this project. After attentively referring to the specifications in the previous researches, material selection, test model designing, printing process and testing was conducted respectively. To have an organized project a flow chart and Gantt chart was made. The flow of the project was clearly shown in the project flowchart whereas the Gantt chart displays the tasks or activity that has been carried out in order to complete this project according to the guideline. This chapter also states the equipment that was used for the whole project. First and foremost was the Ultimaker S5 3D printer, apart from bearing great quality products this printer is also sold at an affordable price. A wide array of industries had utilized this printer in making their prototypes and final products. This printer was connected to a desktop which has the CURA software and all the parameters were set by altering the settings within the software. The product was made layer by layer and the as soon as it has been deposited through the nozzle, the material rapidly solidifies and bond with the previous layer. The test equipment used was the CMM, it uses a probe to measure points on a workpiece. The CMM played a vital role in this project as it was used to check the dimensions of the 3D printed test models and help to determine their dimensional accuracy level. The function generator was used to create assortment of synthesized electrical signal and monotonous waveforms over wide range frequencies. The result obtain will be compared, analyzed and discussed in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter highlights the fine details on the experimental analysis and the result of the dimensional accuracy of the metal printed sample that were printed using the FDM machine. The analysis that were made is to identify the accuracy of metal printed parts using FDM machine while the objective on the other hand is to study the dimensional accuracy of the metal test sample using CMM.

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4.2 Printing Parameters

The preset parameters are given as below in Table 4.1. Specifically, for this project a preset parameter has been pre-determined before the printing process begun. This is to make sure all the filament that is used during this project is not differed by the parameters but solely on their properties of material. By ensuring the parameters are uniform, this will give a better understanding on how the materials would be printed in the given parameters. These parameters have been sliced and simulated using CURA software before being printed to estimate the printing time and to ensure there is no unexpected error occurring while printing the various samples.

Parameters MALAYSIA	Value
Infill Percentage	50%
Infill Pattern	Triangles
Printing Temperature	260.0 °C
Bed Temperature	95.0 °C
51.	· Contraction
Print Speed	45.0 mm/s اوليو مرسيبي
Support Overhang Angle SITI TEKNIKA	90.0 / No support IELAKA

Га	ble	4.1:	Param	eters	of	printed	sampl	le
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4.3 Stainless Steel printed sample result

Table 4.2 below shows the result obtained when the stainless-steel sample were tested using CMM. The table shows the expected accuracy and the actual result obtained. Table 4.3 on the other hand shows the percentage of accuracy when it is printed using FDM relative to the expected accuracy before the printing process. These two tables will help to identify the degree of accuracy that can be used as reference for future metal printing.

Geometry	Expected Accuracy	Actual Result
Thickness (mm)	15	15.20
Hole Diameter (mm)	10	10.05
Angle/Chamfer (°)	135	135.45
Perpendicularity (°)	ەر ىخ ئىكنىكا ما	او نبو ہر س
Corner Radius (mm)	10	10.04
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Width (mm)	22	21.97

 Table 4.2: Expected Accuracy vs Actual Result



Table 4.3: Percentage of Accuracy

Figure 4.1: Stainless Steel Expected Accuracy VS Actual Result

From Figure 4.1, we can identify that Stainless-steel printed specimen were not able to achieve 100% of the dimensional accuracy when it comes to comparison with the expected value that was determined before the experiment. Apart from perpenidcularity, every other dimension struggles with +- 2% from the desired geometry for the stainless steel specimen with thickness having the lowest value of accuracy. Apart from that, the value that have been identified is still in the tolerance range of stainless-steel printed specimen with the given current parameters.



4.3 Tough PLA printed sample result

Table 4.4 below shows the result obtained when the samples were eventually tested using CMM. The right side of the table is the expected measurement data while the left side of the table is the actual data that is recorded using CMM. Table 4.5 on the other hand shows the percentage of accuracy that is displayed by Tough PLA when it is printed using FDM relative to the expected accuracy before the printing process. These two tables will help us identify the degree of accuracy that can be used as reference for future metal printing. For this specific project, the desired geometry measurement for the Tough PLA printed samples are listed out in the previous chapter. The thickness of the sample should be 15mm. The dimeter of the holes should be 10mm. The angle around the chamfer on the other hand should be around 45 Degree. After the testing using the CMM, the perpendicularity of the sample needs to be 90 Degree. The corner radius should be around 10mmand it must also pass the flatness test while having the width around 22mm.

Table 4	.4: Expected Accuracy vs Actual R	esult
Geometry	Expected Accuracy	Actual Result
Sea Amo		
Thickness (mm)	15	15.19
يسيا ملاك	ېتى تېكنىكل مل	اوىيۇس
Hole Diameter (mm)	10 **	9.80
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Angle/Chamfer (°)	135	134.79
Perpendicularity (°)	90	90
Corner Radius (mm)	10	9.80
Width (mm)	22	21.80
1	1	

Та	ble 4.5: Percentage of Accuracy	ý
Geometry	Actual Result	Percentage Accuracy
Thickness (mm)	15.19	98.7%
Hole Diameter (mm)	9.80	98%
Angle/Chamfer (°)	134.79	99.8%
Perpendicularity (°)	90	100%
Corner Radius (mm)	9.80	98%
Width (mm)	21.80	99.1%



Figure 4.2: Tough PLA Expected Accuracy VS Actual Result

From Figure 4.2, it is identified that Tough PLA printed specimen were not able to achieve 100% of the dimensional accuracy when it comes to comparison with the expected value that was determined before the experiment. Apart from perpendicularity, every other dimension struggled with +- 2% from the desired geometry for the Tough PLA specimen with hole diameter and corner radius having the lowest value of accuracy. Apart from that, the value that have been identified is still in the tolerance range of Tough PLA printed specimen with the given current parameters.



4.4 ABS printed sample result

Table 4.6 below shows the result obtained when the samples were eventually tested using CMM. The right side of the table is the expected measurement data while the left side of the table is the actual data that is recorded using CMM. Table 4.7 on the other hand shows the percentage of accuracy that is displayed by ABS when it is printed using FDM relative to the expected accuracy before the printing process. These two tables will help us identify the degree of accuracy that can be used as reference for future metal printing. For this specific project, the desired geometry measurement for the ABS printed samples are listed out in the previous chapter. The thickness of the sample should be 15mm. The dimeter of the holes should be 10mm. The angle around the chamfer on the other hand should be around 45 Degree. After the testing using the CMM, the perpendicularity of the sample needs to be 90 Degree. The corner radius should be around 10mmand it must also pass the flatness test while having the width around 22mm.

Table 4	.6: Expected Accuracy vs Actual R	esult
Geometry	Expected Accuracy	Actual Result
Thickness (mm)	بتي ٽيڪڙيڪل مل	15.09لويتو م
Hole Diameter (mm) ERSIT	TEKNIKA10 MALAYSI/	A MELAK 9.75
Angle/Chamfer (°)	135	135.04
Perpendicularity (°)	90	90
Corner Radius (mm)	10	9.80
Width (mm)	22	21.83

Т	able 4.7: Percentage of Accuracy	
Geometry	Actual Result	Percentage Accuracy
Thickness (mm)	15.09	99.4%
Hole Diameter (mm)	9.75	97.5%
Angle/Chamfer (°)	135.04	99.7%
Perpendicularity (°)	90	100%
Corner Radius (mm)	9.80	98%
Width (mm)	21.83	99.2%



Figure 4.3: ABS Sample Expected Value vs Actual Value

From Figure 4.2, it is identified that ABS printed specimen were not able to achieve 100% of the dimensional accuracy when it comes to comparison with the expected value that was determined before the experiment. Apart from perpendicularity, every other dimension struggled with +- 2% from the desired geometry for the ABS specimen with hole diameter s having the lowest value of accuracy. Apart from that, the value that have been identified is still in the tolerance range of ABS printed specimen with the given current parameters.



4.5 Discussion

Based on the results above, it is safe to conclude that all 3 different types of filaments produced different results when it comes to the final printing dimension. Since the parameters have been set in a controlled state as applied above, the different measurements in the final dimension can be safely concluded as a result of the material properties themselves. All of the three materials produced somewhat accurate printing result with regards to the desired printing parameters that were set before the printing process. There is however no material that able to produce result that achieves 100% accuracy in the result but this can referred to the properties of the materials reacting to the pre-determined parameter although an exception can be made for the perpendicularity aspect of the printing where all 3 materials are able to achieve the desired parameter.

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The design and materials used are the aspects that determine the accuracy of dimensions. It is not advised to use 3D printing for flat surfaces or long, thin, unsupported features. This is the main reason for the support overhang angle being set at 90, which leaves no room for support in the material. In addition, the precision will decrease as the size of the part rises. However, in this instance, the design was not altered; the primary differences are the material and the incorporation of ultrasound. The primary cause for this phenomenon is contraction. Shrinkage might be one of the primary concerns in 3D printing. ABS shrink by around 8 percent as it cools after printing, whereas PLA and metal shrinks by only 2 percent. Both materials were printed at a temperature comparable to one another. Although metal sample's shrinkage comes in a more significant value after the sintering process.

The glass transition temperatures of PLA and ABS are radically different. T_g is one of the most important characteristics of any polymer. The temperature indicates the transition zone between the polymer's hard glassy and soft rubbery states. At temperatures below T_g , the energy of molecular chains decreases. Therefore, they are unable to move. The molecular structure of the polymer is stiff and amorphous. However, the molecules will gain energy when subjected to heat. Stainless steel on the other hand is more rigid and able to withstand temperature up to 315°C and the molecular structure are more susceptible to heat which makes the process smoother although it results in longer printing time due the need of fully melting the particles before assembling it layer by layer on the printing bed.



4.6 Summary

In summary, this chapter highlights the results of different dimensional accuracy of three types of different materials when they are being printed in a controlled parameter beforehand. It is identified that the materials undergo different reactions during both preprinting process and post printing process. This study is conducted in order to study and identify the subjected materials when printing in a vacuum of parameters and how they would react during and after printing using 3D printer. The test results can be identified thoroughly after the process using CMM. The original results of the CMM process are attached in the appendices of the report. This chapter also identifies and compare the result of both the 3D printer and CMM results obtained throughout the study. Based on the charts, it can be observed the samples does not reach 100% accuracy where this is due to the shrinkage after the printing process which is highly applicable to both ABS and Tough PLA. This is especially true for Tough PLA where it has the most significant shrinkage after the printing process. The metal having the least shrinkage on the other hand is mostly due to the properties of material and the shrinkage process usually comes after the shrinkage process.



CHAPTER 5

CONCLUSIONS AND RECCOMENDATION

5.1 Conclusions

The pre-determined parameters and justifications are obtained and identified based on previous journals and study related to the project while at the same time following the optimum parameters from filament's manufacturer suggested parameter. In addition, the optimal parameters such as the raster angle, layer thickness, construction orientation, and air gap are selected as the fixed variables for the entire project based on journal reads and comprehension. Three objectives have been prepared at the start of this project. The first objective is to create CAD drawing of the test model using CATIA V5 drawing software which have been achieved by following:

a) Using the software CATIA, the test model is created. The test model was created and saved as an STL file before transferred to CURA software where the file will be sliced to set the desired parameters and identifying the time needed to print the sample. The design is made by considering all the desired geometry specifically for this project.

The second objective for this project is to 2. To print various type of material sample using Fused Deposition Modelling (FDM) printer.

 a) After slicing the material in CURA software, three material filaments have been prepared for the printing process. The filament is attached onto Ultimaker S5 one by one in order to print all the types of material desired for this project. The third and final objective of this project is to 3. To study the dimensional accuracy of the metal test sample using Coordinate Measuring Machine (CMM).

- a) After the printing process is finished, the sample's dimension was tested using CMM in order to identify the if the sample's dimension achieve the desired parameter's value.
- b) Based on the result obtained, no material has reached 100% of the desired geometry, which was identified due to the shrinkage of the material after the printing process although metal sample has the most similar result to the desired parameter.

5.2 Recommendation

On the basis of this study, even though all of the goals have been completed, there is still opportunity for further improvement that may be incorporated in further research. These are the recommendations that have been made:

- a) The tested dimension can be done on a larger scale of sample and wider range of parameter in order to find the fine line of acceptable parameter for a larger or smaller scale in order to identify the optimum parameter for different size of sample.
- b) Aside from that, additional factors that may be incorporated into the research include the utilization of a variety of FDM machines as well as the introduction of novel materials. The usage of a variety of printers is another possibility for the studies of the future.
- c) Develop an enclosed and heated printing chamber for the 3D printer to prevent quick cooling, which might result in shrinkage and affect the products' dimensional correctness.

5.3 Sustainability Element

The entirety of this research was centered around the idea of identifying the dimensional accuracy of different printed 3D sample. Printing improves productivity and reduces waste, two factors that make it a useful tool in the fight to make production more environmentally friendly. The information and findings obtained, most frequently in the engineering profession and industry, have the potential to contribute to society in a variety of different ways. The market and the underlying technologies are both always subject to change. The field of engineering has broadened its involvement in a variety of other fields, including medicine, agriculture, sports, and many others; this, in turn, has increased the frequency with which it is necessary to make improvements. The following are some of the ways in which this study will contribute to society:

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- a) To begin, a three-dimensionally printed item that has a high degree of dimensional precision and can be manufactured to prevent unanticipated delays in projects. In the business, professional prototypes are frequently employed, and the design of these prototypes can be rather complicated. Typically, they are made up of a wide variety of different pieces that are manufactured using 3D printing technology and then assembled by hand. The precision of the dimensions is of the highest significance since even a little deviation in the production of a single component might create a delay in the completion of the entire project. The costs associated with the project will increase if it is delayed.
- b) Even though the application of this theory is intended for the field of engineering, it is equally applicable to the field of medicine. There is room for maneuverability in terms of design in order to accommodate the utilization of the material. The design process for prosthetics frequently involves customization, which implies that the devices' dimensions and contours need to be tailored to each individual patient. Because of this, it is essential to have an understanding of the benefits of producing an end product with high dimensional accuracy rather than repeatedly rescaling or redesigning the customized parts.

5.4 Life Long Learning Element

On the basis of this research, the aspect of lifelong learning that exists is inside the fact that even after post processing in AM, there are still faults that emerge. In spite of the fact that the majority of users like the traditional activity of measuring, resizing, and reprinting their CAD model, this process is rather time consuming and adds to the generation of waste. By manufacturing things with extremely precise dimensions, this initiative intends to put an end to the behavior described in the following sentence. However, in addition to Stainless Steel, PLA and ABS, there is a wealth of other 3D printing material that may be investigated to see the dimensional correctness of the printed object may be affected with different varying sizes and volume. Any user of a 3D printer can put the information gathered from this thesis to use while manufacturing objects made out of PLA if they so want.

5.5 Complexity Element

This project employs the CMM to measure the dimensions of the samples rather than Vernier Calipers or Smart Scopes. The relative movement of the probe system and the work piece is one of the things that the CMM measures. The answer is arrived at by a series of calculations once the probe has first detected the three-dimensional coordinates of the surface points of the object. When compared to the other pieces of equipment, the CMM's sensitivity is light years ahead of the competition. This demonstrates that it is able to identify even a minute shift in the measurement of the product's dimension, which is a significant accomplishment. Due to the relatively high cost of the CMM, it is essential that it be treated with the utmost care at all times. In addition to problems with calibration, the probe of the CMM is frequently subjected to stress. In order for the users to first manually manipulate the probe in order to locate the starting point, it is necessary for the users to exercise cautious control over the probe. If the probe is subjected to a direct force, it has the potential to break, in which case a replacement probe will need to be purchased.

5.6 Summary

In conclusion, every one of the goals that were set for this project has been accomplished. The first objective, which is to design and create CAD drawing using CATIA software have been accomplished in the first part of the project here the drawing is completed. The second objective, to print various type of material sample using FDM printer have also been achieved here three types of material have been printed which is Stainless steel, Tough PLA and ABS. The drawing was sliced first beforehand using the CURA software before inserting the data into Ultimaker S5 where the samples as printed individually according to the parameters that determined beforehand. The third objective, to study the dimensional accuracy of the metal test sample using CMM have also been achieved. The test using CMM have been conducted after the printing process where the machine uses probe to identify the accurate dimension of the sample. The results have been tabulated and compared after the test data of all samples have been collected. Despite this, there is still opportunity for development in the studies that will be conducted in the future. For example, more geometry can be examined, and additional analysis can be conducted regarding the dimensional accuracy of the test model that was 3D printed. Finally, this project seems to have a vast amount of versatility in terms of data collection, as it incorporates all of the essential aspects of engineering from the early stages down to the minute details in the end of the study.

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APPENDICES

Start ENOVIA V5 VPM <u>File</u>dit <u>V</u>iew Insert <u>T</u>ools <u>W</u>indow <u>H</u>elp Part1 1 🚄 xy plane 韵 🗾 yz plane 🗾 zx plane aT - 🔅 PartBody ් ් X*** 44 🔊 🖸 🔐 👘 🕲 🦓 **R**? DS

1. CAD Drawing from CATIA Software

2. STL file slice in CURA Software



3. CMM Data for Stainless steel

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5. CMM Data for ABS

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