ANALYSIS OF DIMENSIONAL ACCURACY AND SURFACE FINISH PERFORMANCE FOR A 3D PRINTER BASED ON FDM TECHNIQUE

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

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Engineering Design) (Hons). The member of the supervisory committee are as follow:

……………………................................

(Dr. Zulkeflee Bin Abdullah)

ABSTRAK

Pembuatan bahan tambahan adalah satu teknologi baru untuk mempercepatkan penghasilan produk. FDM adalah salah satu teknologi pembuatan bahan tambahan yang paling popular dan digunakan secara meluas untuk menghasilkan prototaip. Walau bagaimanapun, dimensi ketepatan dan permukaan kekasaran pencetak 3D FDM sentiasa tidak memberikan pengukuran yang konsisten dan tepat kepada produk yang dihasilkan. Terdapat banyak faktor yang mempengaruhi dimensi ketepatan dan kekasaran permukaan termasuk 'tessellation' yang dihasilkan oleh perisian yang digunakan. Tujuan projek ini adalah untuk menganalisis ketepatan dan permukaan prestasi penamat dimensi untuk pencetak 3D berdasarkan teknik FDM. Objektif projek ini adalah untuk mengkaji dan menggunakan tiga model pencetak 3D FDM iaitu Mojo, Up Plus 2 dan Creator Pro. Seterusnya, untuk membandingkan ketepatan dan permukaan penamat tiga dimensi model pencetak 3D FDM, dan juga untuk menyiasat hubungan ketepatan dimensi dan kemasan permukaan antara pencetak 3D. Semua pencetak 3D adalah pada aras yang sama iaitu dari aras pemulaan kepada peringkat pertengahan. Setiap pencetak 3D menghasilkan dua keping spesimen dari Solidworks 2013 dan dua spesimen perisian Catia V5R19. Rujukan telah digunakan untuk rekaan bentuk bahan kerja. Penguji kekasaran permukaan dan CMM telah digunakan untuk mengukur kekasaran permukaan dan ketepatan dimensi bahan kerja masing-masing. Keputusan mendedahkan bahawa setiap pencetak 3D yang dihasilkan berbeza dimensi ketepatan dan kekasaran permukaan walaupun bahan ABS dan beberapa parameter seperti ketebalan lapisan, membina orientasi dan sudut raster telah ditetapkan kepada setiap pencetak 3D. Akhir sekali, pencetak 3D yang menyediakan kekasaran permukaan halus dan ketepatan dimensi yang paling tepat di antara tiga pencetak 3D telah dianalisis.

ABSTRACT

Additive manufacturing is an innovation for rapid technology to speed up the product development. FDM is one of the additive manufacturing technology which is most popular and widely used for production application and prototyping. However, the dimensional accuracy and surface roughness of FDM 3D printers are always not provide consistent and precise measurement of the product being produced. There are a lot of factors that affecting dimensional accuracy and surface roughness include tessellation produced by the software used. The purpose of this project is to analyze the dimensional accuracy and surface finish performance for a 3D printer based on FDM technique. The objectives of this project are to study and utilize three models of FDM 3D printer which are Mojo, Up Plus 2 and Creator Pro. Next, to compare the dimensional accuracy and surface finish of three models FDM 3D printer work piece, as well as to investigate the relationship of dimensional accuracy and surface finish between 3D printers. All these 3D printers are at the same range which are from beginner to intermediate level. Each 3D printer built twice work piece from Solidworks 2013 and twice from Catia V5R19 software. Benchmarking feature identification has been referred as a work piece design. In this project, surface roughness tester and CMM have been used to measure the surface roughness and dimensional accuracy of the work piece respectively. The results revealed that the each 3D printers produced different dimensional accuracy and surface roughness even though ABS material and some parameters like layer thickness, build orientation and raster angle have been fixed to each 3D printer. Lastly, 3D printer that provides the smoothest surface roughness and the most accurate dimensional accuracy among these three 3D printers have been analyzed.

DEDICATION

I would like to dedicate this work to my

Beloved parents

Dearest siblings

Honorable supervisors and lecturers

Supportive friends and mates

For giving me moral support, money, cooperation, encouragement and also understandings.

May ALLAH bless all of us.

Ameen.

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In the name of ALLAH, the most gracious, the most merciful.

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Author,
[Amirah Afina Johari Faisal Stephen]

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive Manufacturing
AMC	-	Advanced Manufacturing Center
AFOs	-	Ankle Foot Orthoses
CAD	-	Computer-aided design
CMM	-	Coordinate Measuring Machine
CNC	-	Computer Numerical Control
EBM	-	Electron Beam Melting
FDM	-	Fused Deposition Modeling
FKP	-	Fakulti Kejuruteraan Pembuatan
FOs	-	Foot Orthoses
LOM	-	Laminated Object Manufacturing
O&P	-	Orthoses and Porthoses
PLA	-	Polylactic Acid
Ra	-	Roughness Average
RP	-	Rapid Prototyping
SLA	-	SLA
SLS	-	Selective Laser Sintering
SOP	-	Standard of Procedure
STL	-	STereoLithography
UTeM	-	Universiti Teknikal Malaysia Melaka
3D	-	3 Dimension

CHAPTER 1

INTRODUCTION

Chapter 1 provides a brief explanation about this project, the background of the project title, "Analysis of dimensional accuracy and surface finish performance for a 3D printer based on FDM technique" and will discuss the problem statement, objectives and scope of the project.

1.1 Background

Masood *et al.,* (2016) pointed out that Fused Deposition Modeling (FDM) is an Additive Manufacturing (AM) technology which can construct physical models from Computer Aided Design (CAD) software automatically by using layers deposition of extrusion materials. In fact, FDM is one of the additive prototyping processes which can generate a prototype from plastic material by laying track of semi molten plastic filament on to a platform in a layer from the top to bottom. The layer generation result from solidification is because of heat conduction. Besides, reduction in cycle time of product development is a major consideration in industries to remain competitive in the market place. Therefore, conventional process development technology has been changed to rapid fabrication techniques, for example, additive prototyping processes.

The main purpose of this project is to analyze the dimensional accuracy and surface finish performance for a 3D printer based on FDM technique. Since there are various 3D printer machines in UTeM, especially in Main Campus, experiments will be conducted using three types of machines which are Mojo, UP Plus 2 and Creator Pro located at Rapid Prototyping Laboratory. All of these machines are from beginner to intermediate level but have different specifications, pros and cons (3D Hubs, 2016). Each work piece produced have been drawn by two different types of CAD software which are Solidworks 2013 and Catia V5R19. The 3D printer will be ranked according to the part or product quality produced based on their dimensional accuracy and surface roughness.

1.2 Problem Statement

Boschetto & Bottini (2016) pointed out that, FDM is the technology of additive manufacturing that is capable to create model, tooling and functional parts without geometrical complexity restrictions. In spite of the possible favorable aspects of this innovation, obtaining a precise accuracy is hard to achieve. This includes poor surface quality. Islam *et al.,* (2013) have mentioned that 3D printed work piece commonly have dimensional accuracy and surface finish problems. Besides, parts produced by different 3D printers have varied accuracy and surface finish. The parts that not meet the design specifications according to the standard will affect the performance and the assembly fit with other components. All 3D printer machines have their own specifications and some of them do not provide consistent and precise measurement of the product being produced. By using three types of different FDM machines, the work piece produced from each machine will be compared through their dimensional accuracy and surface finish.

,

1.3 Objectives

The objectives of this study are as follows:

i. To study and utilize three models of FDM 3D printer; Mojo, UP Plus 2 and Creator Pro.
ii. To compare the dimensional accuracy and surface finish of three models FDM 3D printer work piece.
iii. To investigate the relationship of dimensional accuracy and surface finish between 3D printers.

1.4 Scope

The scope of this project focuses on the analysis regarding dimensional accuracy and surface finish performance for a 3D printer based on FDM technique. The sample of a model is drawn using Solidworks 2013 and Catia V5R19 software according to the benchmark evaluation from Johnson *et al.,* (2011). All work pieces drawn will be converted into STL files to be readable by FDM machines. In this project, three machines; Mojo, UP Plus 2, and Creator Pro will be compared to investigate the relationship of dimensional accuracy and surface finish between 3D printers. Each machine will produce two work pieces from each software and average will be calculated to get the accurate data. The material used in the FDM process is ABS thermoplastic material. The work piece surface roughness are measured using surface roughness tester in FKP Ground Floor, Block B, Metrology Laboratory. After the surface finish of the product has been measured, each work pieces are determined using Coordinate Measuring Machine (CMM) to measure the accuracy of the work piece by comparing it with actual drawing from CAD data software. All work pieces are examined under Meiji Stereo Microscope located at FKP Ground Floor Block B, Metrology Laboratory to determine the difference in structure. All the data will be recorded. The three different FDM machines will be ranked according to their level of accuracy part produced.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the related knowledge of the project which cover the introduction of the Additive Manufacturing, Fused Deposition Modeling, dimensional accuracy and surface roughness.

2.1 Additive Manufacturing

Technologies, Medium, & Powell (2008) mentioned in worldwide competition, most of the companies are seeking for the new technologies to improve their business processes and speed up the product development cycle due to the demands for cost savings. One of the key enabling technologies with its competence to minimize the product design and development time involves using the technology of Rapid prototyping (RP) also known as Additive Manufacturing (AM).

AM is an innovation for rapidly fabricating physical models, functional prototypes and limited batches of parts directly from Computer Aided Design (CAD) data. Besides, AM also refers to the three-dimensional (3D) printing, build techniques layer-by-layer, material addition manufacturing, and solid free-form fabrication. AM shortens the time-to-market of products and enlarges technology competitiveness.

Guan *et al.*, (2015) also stated that AM is now experiencing an advanced application in prototype and pilot production innovation towards versatile and high-value manufacture aspects.

Barner (2015) also added in most cases layer by layer following a build-up code, objects with hollow spaces, undercuts or complete assemblies are feasible because AM is straightly derived from a three-dimensional model, similar to modern CNC manufacturing. The only difference is that materials are not removed, but rather plotted and no tool is required.

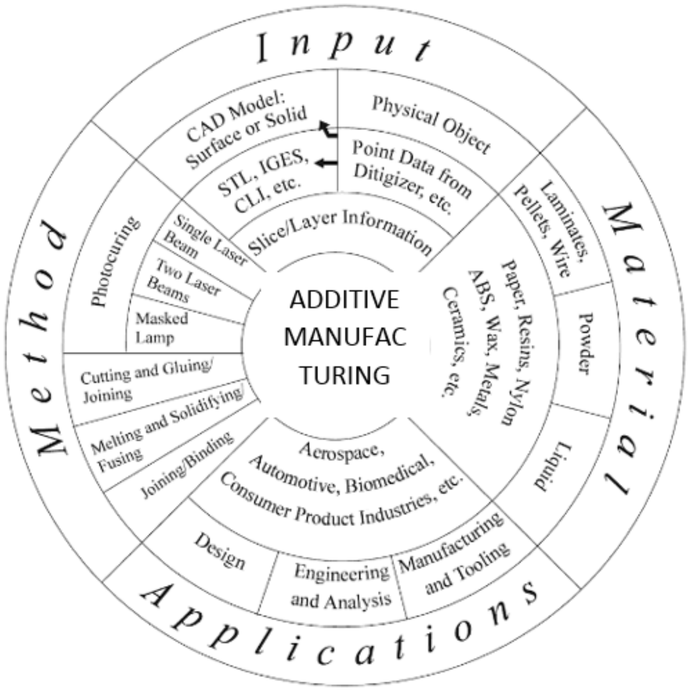

Figure 2.1: Wheel illustration the four major aspects in AM (Chua *et al.,* 2010).

Figure 2.1 shows the four major aspects in AM which are the methods, applications, material and input.

2.2 Eight Generic AM Processes

From Figure 2.2, there are 8 steps needed to generate a part for FDM machine.

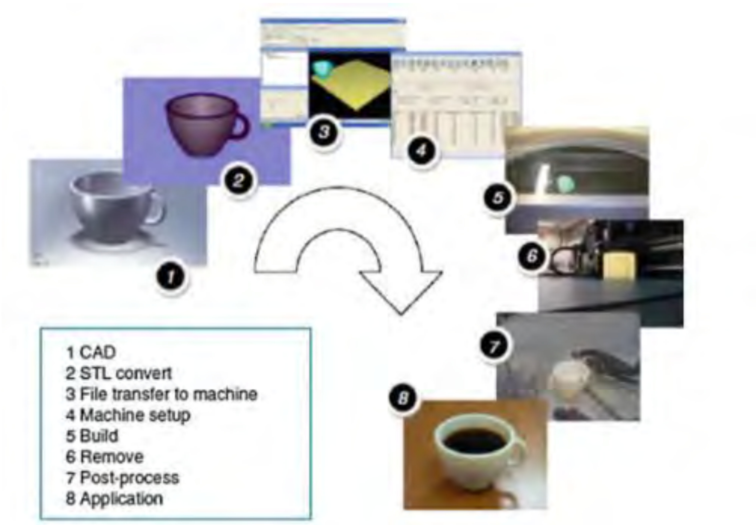

Figure 2.2: Eight Generic AM Processes (Gibson, Rosen, & Stucker, 2010).

1st Step: CAD

First step of the AM process must begin from a product model created using any CAD solid modeling software or reverse engineering equipment using laser scanning equipment (Gibson *et al.,* 2010).

2nd Step: Conversion to STL

The second step is to convert the CAD data into the STL file. Almost every AM machine recognize the STL file that has turned into an accepted standard. They are sliced into thin cross-sectional layers (Gibson *et al.,* 2010).

3rd Step: Transfer to AM machine and STL File Manipulation

Once the STL file has been created, it can be sent directly to the AM machine to build the part straight away. In some cases, there will be a few adjustments and actions required prior to building the part (Gibson *et al.,* 2010).

4th Step: Machine Setup

All AM machines must be appropriately set up for parameters that are specific to that machine or process. Some machines settings would identify with the required optimization like material used, infill pattern, z resolution and part angle (Gibson *et al.,* 2010).

5th Step: Fabrication of the part

The AM machine should be monitored although the fabrication of the part is an automated process to avoid power failure or running out of materials throughout the FDM process (Gibson *et al.,* 2010).

6th Step: Removal of Part

The part should be removed once the FDM procedure is finished. A portion of the part created can be removed with the guide of devices. This often involves manually removing the part from the machine, cleaning off the support structure and removing the excess material which requires much time and skill (Gibson *et al.,* 2010).

7th Step: Post processing

After the part is removed, they may require some completing of the parts before they are prepared to be utilized. Cleaning, sandpapering, paintings and coatings are done to give a good surface finish (Gibson *et al.,* 2010).

8th Step: Applications

Although parts may be made from similar material with conventional manufacturing, some parts may fail under mechanical stress due to small voids or bubble trapped while being built (Gibson *et al.,* 2010).

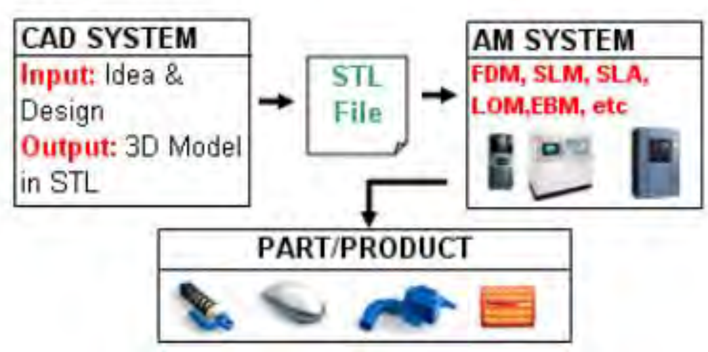

Figure 2.3 Steps in AM from design to manufacturing (Moroni, Syam, & Petró, 2014).

Figure 2.3 shows the steps in AM. It begins from CAD system, next the CAD need to convert into STL file. Subsequently, STL file is transfer to AM system, then only the part or product can be generate.

2.3 Application of AM

AM has developed rapidly and its application has extended from prototyping to conceivable end-use items. This can be demonstrated in Figure 2.4.

Timeline	Emerging Technology
1988 -1994	*rapid prototyping*
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013-2016	nano-manufacturing
2013-2017	architecture
2013-2018	biomedical implants
2013-2022	in situ bio-manufacturing
2013-2032	fullbody organs

Figure 2.4 AM application timeline (Royal Academy of Engineering, 2013).

Figure 2.4 shows the application timeline of AM. It has begun from 1988 and looking forward on their future potential until 2032.

Medical, aerospace and automotive applications in AM are explained below.

a) Medical application

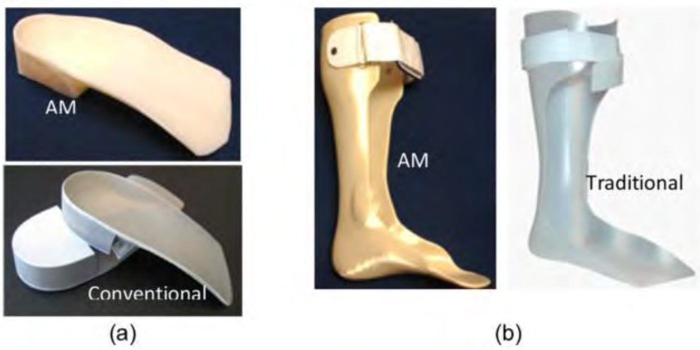

Figure 2.5: Orthoses and Prostheses (O&P) illustration of fabricated part using the traditional and AM: (a) foot orthoses and (b) ankle-foot orthoses (Chen *et al.*, 2016).