MECHANICAL PROPERTIES INVESTIGATION OF 3D PRINTED PARTS UNDER THE EXCLUSION OF OXYGEN

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A reported submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering (BMCG)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this project report entitled "Mechanical Properties Investigation of 3D Printed Parts Under the Exclusion of Oxygen" is the result of my own work except as cited in the references.

Signature: ……………………………………………………….

Name: ……………………………………………………….

Date: ……………………………………………………….

APPROVAL

I hereby declare that I have read this project report and, in my opinion, this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature: ………………………………………

Name of Supervisor: ………………………………………

Date: ……………………………………….

ABSTRACT

In order to obtain the prototype in shorter times and in cost-effectiveness, 3D printing, also known as additive manufacturing (AM), have been introduced. AM is also capable of manufacturing complex part geometry without any additional tools and jigs. Fused deposition modeling (FDM) is one of the most popular techniques in AM. However, its design manufacturability and printed parts quality are the main limitations of FDM in terms of surface roughness, flexural strength and dimensional accuracy. In this research, the 3D printing process method using FDM were being discussed to examined the effect of pre-processing and in-processing techniques on mechanical properties which is specified on the surface roughness and the manufacturability of an open source 3D printing machine. As for the pre-processing, Taguchi analysis was conducted to determined the optimal printing parameter setting. Additionally, for in-processing technique, inert gas had been introduced to control thermal degradation as for the atmosphere condition to exclude the presence of the oxygen in the 3D printing chamber. Based on the comparison made, inert gas presence in the 3D printing chamber was selected at the best improvement techniques because of its capability to improve the whole printed parts quality including surfaced roughness, tensile strength and dimensional accuracy. In general, it was found that, the 3D printed parts surface roughness was improve by 48.29% for nitrogen ambient on 3D printer condition comparing to the oxygen ambient. For the Ra value of the optimum result for the surface roughness on the oxygen ambient which is 1.3667μm while the nitrogen ambient is reduce to 0.7067μm show the result for the in-processing method were significantly reduces. This study has proven that the improvement method during in-processing technique are better on the exclusion of the oxygen.

ABSTRAK

Untuk mendapatkan prototaip dalam masa yang lebih singkat dan mengurangkan kos secara efektif, percetakan 3D, juga dikenal sebagai pembuatan secara tambahan telah diperkenalkan. Percetakan 3D juga mampu menghasilkan geometri bahagian yang kompleks tanpa alat dan jig tambahan. "Fused deposition modelling" (FDM) adalah salah satu teknik yang paling sering digunakan dalam percetakan 3D. Walau bagaimanapun, kemampuan reka bentuk dan kualiti bahagian yang dicetak mempunyai had batasan dari segi kekasaran permukaan, kekuatan dan ketepatan dimensi. Dalam penyelidikan ini, kaedah proses pencetakan 3D menggunakan FDM, dibincangkan untuk mengkaji pengaruh teknik pra-pemprosesan dan pemprosesan pada sifat mekanikal yang diperolehi pada dapatan kajian dari aspek kekasaran permukaan dan pembuatan mesin cetak 3D sumber terbuka. Selain itu, untuk pra-pemrosesan, analisis Taguchi dilakukan untuk menentukan pengaturan parameter pencetakan yang optimum. Selain itu, untuk teknik pemrosesan, gas lengai telah diperkenalkan untuk mengendalikan degradasi termal dan kondisi atmosfera untuk mengecualikan kehadiran oksigen di ruang percetakan 3D. Berdasarkan perbandingan yang dibuat, kehadiran gas lengai di ruang percetakan 3D dipilih dengan teknik penambahbaikan terbaik kerana kemampuannya untuk meningkatkan keseluruhan kualiti bahagian yang dicetak dalam aspek kekasaran permukaan, kekuatan tegangan dan ketepatan dimensi. Secara amnya, kajian mendapati bahawa kekasaran permukaan bahagian bercetak 3D meningkat sebanyak 48.29% untuk percetakan 3D yang dibantu oleh gas lengai nitrogen berbanding dengan percetakan 3D yang mempunyai kehadiran oksigen. Nilai yang diperolehi bagi kekasaran permukaan (Ra) hasil yang optimal untuk percetakan 3D yang mempunyai kehadiran oksigen ialah 1.3667µm berbanding percetakan 3D yang dibantu oleh gas lengai nitrogen yang berkurang sebanyak 0.7067µm menunjukkan hasil untuk kaedah pemprosesan berkurang dengan ketara. Kajian ini telah membuktikan bahawa kaedah penambahbaikan semasa teknik pemprosesan adalah lebih baik dengan pengecualian oksigen.

ACKNOWLEDGEMENTS

In the name of Allah S.W.T , the Most Gracious and the Most Merciful, *Alhamdulillah,* praise to be Him. First and foremost, I would like to take this opportunity to express my deepest gratitude towards my supervisor, Dr Faiz Redza Bin Ramli from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his constituent supervision, support and encouragement towards the completion of this studies.

I would like to extend my acknowledgement to my personal academic advisor Profesor Madya Dr Mohd Juzaila Bin Abd Latif from Faculty of Mechanical Engineering for his indirect involvement for this studies along my years in UTeM.

Last but not least, special thanks to my parents especially my mother, Puan Hjh Halimah Bte Zayadi, my siblings, my peers, and my fiance for their support in terms of emotional and financial in completing this Bachelor’s degree. Lastly, thank you to every person that involve directly or indirectly throughout this studies.

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AM	Additive Manufacturing
3D	Three Dimensional
FDM	Fused Deposition Modelling
ABS	Acrylonitrile Butadiene Styrene
PLA	Polylactide Acid
CAD	Computer Aided Design
STL	Standard Tessellation Language
ASTM	American Society for Testing and Materials
DFM	Design for Manufacturability
S/N	Signal to noise ratio
N_2	Nitrogen gas
O_2	Oxygen gas

LIST OF SYMBOL

F	=	Force
σ	=	Stress (sigma)
A	=	Area
ε	=	Elongation
E	=	Elastic Modulus
T_m	=	Melting Temperature
T_g	=	Glass Transition Temperature

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Additive Manufacturing (AM) is defined as the process of joining materials to make a product geometrical three-dimensional (3D) shape based on design data on computer aided design (CAD) that operate a layer upon layer additive fabrication which is also referred as 3D printing. Nowadays, the industry had been developed from the conventional machining such as casting and forging processes which is need more labour work into a single computer monitor controller. 3D printing has contributed to many industries such as automotive, aerospace and biomedical fields. Freedom of design and limited material selection are some of advantage and limitation in 3D printing.

The Fused Deposition Modelling (FDM) technique has proven up to be the best printing technology and FDM printers are broadly reachable in the industry at present. The product parts are generated by extruding small drop of material which harden immediately to form layers. A filament of thermoplastic, metal wire, or any different material is fed into an extrusion nozzle head, which heats the material and turn the flux on and off. FDM is really restricted in the variant of shapes that may additionally be fabricated.

Consequently, the use of polymers with a high mechanical load tolerance such as acrylonitrile butadiene styrene (ABS) is favoured and special polymers are available for the production of mechanically resistant parts, such as specialized nylon filaments. During the FDM process, the polymer filament is molten at a comparatively high temperature and layer by layer printed on a printing bed. Typically, the layer height is within the range of a few hundred micrometers, resulting in a large surface area of the hot polymer exposed to air during the printing process. This is in contrast to other manufacturing processes such as injection molding. As the expected result, each layers of polymers surface is suspected to degrade during the printing process which may influence the mechanical properties.

1.2 PROBLEM STATEMENT

Although AM has given many potential and advantages, the technology has a various relevant factor that could damage its formulation. The inadequate design guidance for AM is one of the limiting factors, especially in the FDM system (Adam et al. 2014). Furthermore, the manufacturing capability of the FDM system in terms of the mechanical properties of the printed parts is not achieved as high quality compared to the other AM technology. The performance of the FDM parts became of main consideration to the manufacturer and users, and the characteristics of the FDM part, such as tensile strength, flexural strength, compressive strength, dimensional accuracy, surface roughness, build time, yield strength and ductility, are often being discussed (Omar et al. 2015). Research studies suggested a technique aimed at finding optimal process parameters to improve the cultural value of the printed part elements in terms of surface finishing, quality in terms of mechanical properties, material usage and fabrication time of design (Nachariah et al. 2010). After all, there is still no best choice of process parameters for all kinds of materials. Typically, FDM process parts have lower mechanical properties by comparing conventional manufacturing processes such as injection molding.

There is a constrain in the AM system on the type and properties of the materials which could be manufactured. Several experiments have been carried with a view to systematically analyzing failures and the quality of designs, depending on each set of parameters that will identify the effect of part quality using the suitable approach (Nachariah et al. 2010). Part accuracy develops on AM techniques and has led to significant research problems. Optimization of the process parameter is a major challenge for accuracy, roughness and finishing and fabrication time for development (Galantuci et al. 2015). Further than that, as the ability to withstand deformation under load-printed components, flexural strength is an essential aspect of FDM technology that enables the components to work longer.

Several studies have been conducted over the last few years to improve the mechanical properties and aesthetic value of the FDM printed part by acceptable alteration of process parameters, however the findings didnt focus on the set of in-process techniques designed to improve the quality of the 3D printed part. Of starters, owing to specific factors, specific oxidation processes occurring in polymers contribute to substance degradation at higher temperatures in the presence of oxygen. In most situations, the polybutadiene stage (which affects the active two-fold bonding) is affected by oxidation reactions, which result in a high significant reduction in mechanical properties (Lederle et al. 2016).

Here, the investigations will introduce a short examination of FDM printed parts at typical activity conditions contrasted with the printing procedure performed under the severe avoidance of oxygen. The report on a serious improvement of the mechanical properties, for example, yield quality if the print is performed inside an enclosure overflowed with nitrogen. The upgraded properties of parts printed under inert gas conditions were found as the print of response vessels for most oxygen will performed under the inert gaseous. The strategy exhibited here may prompt a fairly straightforward improvement of FDM printers.

1.3 OBJECTIVE

The main objective of this research is to get the comparison on mechanical properties of 3D printed parts between the manipulated variable of chamber condition to study the effect on the presence of oxygen which is between the normal process and inert gas assisted 3D printed parts. Hence, the specific aim are:

I. To design and fabricate an enclosure box in addition to flooding the inert gas into 3D printer machine and develop a suitable guideline for 3D printer for FDM technique.

II. To study the effect of improvement method during in-process technique on mechanical properties of 3D printed parts using two different conditions.

III. To compare between mechanical properties of 3D printed parts and determined which technique get better quality.

1.4 SCOPE OF PROJECT

This project is carried out experimentally. A simple model has been developed using cheap available materials to assist the nitrogen flooding the 3D printing machine. The project is mainly focused on the study of mechanical properties and some mechanical testing is conducted to determine the printed parts quality. The evaluation of the testing is from standard testing method according to ISO standard which is ASTM D638 for universal testing procedure. Process parameter that being choosen are the most crucial parts which are, layer thickness, infill density, and raster angle. The machines involve for the mechanical testing are as below:

I. Surface roughness : Using TR200 Surface Roughness Tester Profilometer

II. Surface image : Using 3D Non Contact Profilometer, to get the data profile of surface arrangement of printed parts.

The studies are using an open source 3D printer. 3D printer model used in this experiment is A8 3D Printer. The material used through the experimental study is thermoplastic material, Polylactic acid (PLA).

CHAPTER 2

LITERATURE REVIEW

2.1 Additive Manufacturing

Additive Manufacturing (AM) is a concept used to define techniques that create 3D structures by incorporating layer-by-layer material created from plastic, metal or concrete products. The usage of machines, 3D CAD design tools, process machinery and layering materials is essential to these developments. AM developments started in the 1980s to produce components in specific design by implementing CAD and Computer Aided Manufacturing (CAM) (Luzanin et al. 2014). Figure 2.1 shows the 3D printing full process from the model design to the finished parts which is considered as the additive manufacturing (AM) known as 3D printing.

AM technology considering a three process flow:

1. The pre-processing which is a computer aided design (CAD) in 3D solid model is developed and converted into a standard AM file format such as the traditional standard tessellation language format or the recent additive manufacturing file format.
2. The printing process which is a file is sent to an AM machine where it is manipulated by the machine and the part is built layer by layer on the AM machine.
3. The post processing which is cleaning or deburring debris on the surface of the finished part.

Figure 2. 1: Flowchart of 3D Printing Process

AM is known as 3D printing but in actuality, this designation is a subset of the AM concept. In all, there are seven types of AM established by ASTM under the Standard Terminology for Additive Manufacturing Technologies. The seven types of AM and their use are shown in Table 2.1 and Figure 2.2 show the schematics diagram of the types of additive manufacturing process.

Table 2.1: Types of Additive Manufacturing and it definitions

(Source: Piazza & Alexander, 2015)

1) Binder jetting	AM process where a liquid bonding agent is deposited to join powdered materials together.
2) Direct energy deposition	AM process where thermal energy fuses or melts materials together as they are added
3) Material extrusion (fused deposition modeling)	AM process that allows for depositing material via a nozzle
4) Material jetting	AM process where droplets of material are deposited
5) Powder bed fusion (laser sintering)	AM process where thermal energy fuses or melts material from a powder bed
6) Sheet welding	AM process where sheets of materials are bonded together
7) Vat photo-polymerization	AM process where liquid photopolymer in vat is cured by light.

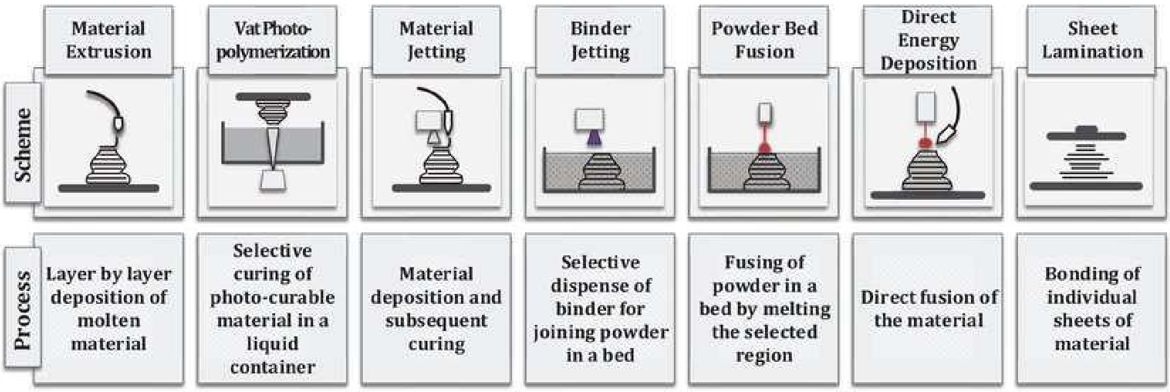
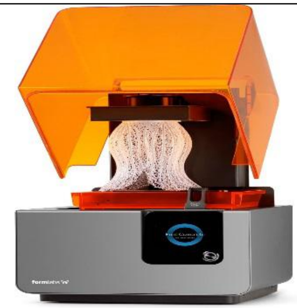
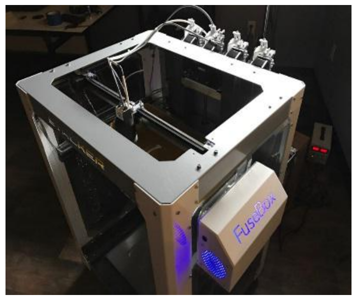


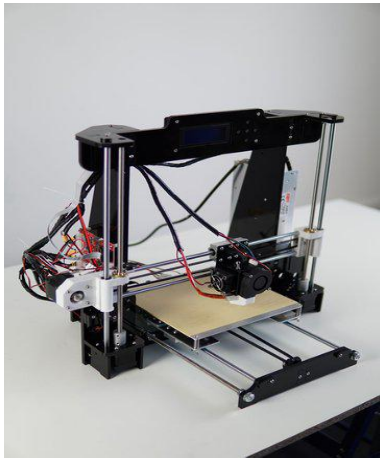
Figure 2.2 : Method of 3D printing

(Source: Perrot & Amziane, 2019)

Table 2.2 listed the comparison that have been made between different techniques of additive manufacturing technology. The technologies that were describes such as stereolithography (SLA), laminated object manufacturing (LOM), selective laser sintering (SLS), and fused deposition modelling (FDM). In the meantime, the comparison had been made between the method of 3D printing as shown in Table 2.3 which is covered the material description, product quality and design complexity.

Table 2.2:Comparison of additive manufacturing technology

AM System	Description	3D Printer Machine	References
Streolithography (SLA)	• The first technique in AM • The process converted liquid plastic into solid 3D objects. • Once all layers are printed the object was rinsed with a solvent chemical and place in an oven to post-process treatment.		William et al.1998
Laminated Object Manufacturing (LOM)	• Layers of adhesive coated paper, plastic or metal laminated are combine together and by using heat and pressure to laser or knife.		Spancer et al.1993
Selective Laser Sintering (SLS)	• Uses laser as power source to form solid 3D objects • SLS doesn’t need to use any support structure as because the printed part was placed on un-sintered powder.		Gornet et al. 2014

Fused Deposition Modelling (FDM)	• Usually, mid end technology always refers the FDM technique in which the parts are built through layer by layer concept, However, the differences between low cost FDM printer and Mid-end printer is its designated with the casing. By providing the casing, the temperature and ambient temperature can be controlled		Gornet et al. 2014
	• FDM having the poor quality in mechanical properties which is included surface roughness, mechanical strength and less dimension accurate compare to high end technology.		Wohler et al. 2013